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POWER AND INFLUENCE

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Disclaimer

2025 is a study designed to comply with a directive from the chief of staff of the Air Force to examine the concepts, capabilities, and technologies the United States will require to remain the dominant air and space force in the future. Presented on 17 June 1996, this report was produced in the Department of Defense school environment of academic freedom and in the interest of advancing concepts related to national defense. The views expressed in this report are those of the authors and do not reflect the official policy or position of the United States Air Force, Department of Defense, or the United States government.

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Preface

Power undirected by high purpose spells calamity; and high purpose by itself is utterly useless if the power to put it into effect is lacking.

—Theodore Roosevelt

Ultimately, the test of national defense is the ability to apply military force unilaterally in support of the national interest. The array of power at the nation's disposal in support of its interests is crucial to national security. The power that the USAF can employ—both lethal and nonlethal—in the worlds of 2025 is critical to the nation's ability to survive and prosper in a complex, interdependent, constantly changing security environment. That power has many different dimensions—tactical or strategic, conventional or nuclear, command and control or informational, and chemical or biological. The nature of the force available in 2025 will determine the effectiveness of the power of the United States in 2025. Hence, force-structure decisions made now are crucial to the strategic environment of the future.

But power—the application of force, the utilization of military capabilities—is only an instrumental goal. What we really seek is influence—the ability to produce effects on others, directly or indirectly. We want to change an adversary's perceptions, cost-benefit calculations, and action or inaction in accord with our desires. We seek to influence people to make certain choices. The use of power in the application of force is merely one way to do this. Having the power—the force—to compel is a means to deter. We don't use power directly, but we have it, and our possession of certain systems and capabilities may indirectly cause an adversary to change his mind on a course of action. What we seek is not so much global power as global influence. In Douhet's terms, we seek to destroy the enemy's will to resist. That may be done by destroying his capability to resist. But it need not be. All we need do is influence his decision processes.

The papers in this volume investigate numerous systems, technologies, and concepts of operations by which the United States may maintain or increase its technological superiority to leverage asymmetrical advantage in conflict with nearly any adversary to preserve American security in the twenty-first century. Some of these notions may seem rather outlandish and more akin to science fiction than serious military planning. But one must remember that the technology of the future may verge on the incomprehensible. Any speculation about the technology of 2025 that does not seem like magic is probably flawed.

(Please note that appendix A contains a list of all the papers in the ***2025*** study, arranged by volume for ready reference. Also, appendix B contains a list of all the people—military and civilian, warriors and scientists, educators and operators, leaders and supporters—who contributed to the ***2025*** project.)

Surfing the First and Second Waves in 2025: A Special Operations Forces Strategy for Regional Engagement

"A *2025* Connecticut Yankee in King Arthur's Court?"

Lt Col Thomas F. Berardinelli
Maj Sandra R. Bignell
Maj Michael J. Irwin
Lt Comdr Alfredo E. Rackauskas (USN)

Executive Summary

The United States is riding high on the crest of "third wave" technology as it leads the world's rush into the Information Age. It must not become so fixated on the information-based future that it is unprepared to deal with 78 percent of the world's population who will still be living in preindustrial and industrial societies late into the twenty-first century.[1] Our thesis is that Special Operations Regional Engagement (SORE) forces will be the United States' warriors prepared to successfully engage in these less developed, though no less threatening worlds of the first- and second-wave "the 'Niche Warriors' of 2025." Their timeless core competencies—skill in the use of unconventional equipment and tactics, excel in politically sensitive environments and operations, employ unorthodox approaches, exploit limited opportunity, and produce/use specialized information—make them "special" and distinguish them from conventional forces.

These core competencies underlie SORE-unique and specialized skills that make them the force of choice to meet this challenge. First, they possess the cross-cultural skills that will remain elusive for many but are needed to build and gain the trust of these underdeveloped nations—foreign language proficiency, cultural and area awareness, nonverbal communications, and interpersonal skills.[2] Second, they "blend" into the environments in which they operate, either using their cross-cultural skills or the new third-wave technologies at their disposal. Third, SORE forces are not employed to "fight the client's battle" but to train them to "defend themselves" without developing a dependency on SORE forces. There is a critical air power component to SORE that the Air Force must prepare itself to meet. Many first- and second-wave entities will face threats to their internal security that may require the proper use of air power. The fledgling air forces of these entities will require assistance in developing adequate tactics, procedures, maintenance, supply, and other support systems within their own technological limitations. Last, since conventional forces will no longer possess the expertise, the weapons or the equipment found in most of these first- and second-wave areas, it will be the responsibility of SORE forces to be the "experts" in the procedures, tactics, and support requirements necessary to prevent and counter the spreading threat that "outbreaks of small wars" pose to US national interests.

SORE activities are conducted across the spectrum of military operations, from peace to war, and focus their defensive and offensive operations on training, advising, and assisting. The defensive objective is to enable host nations or other internationally recognized entities to maintain their internal security against forces that promote lawlessness, subversion, and terrorism, using their own

personnel and equipment. Although ideally conducted in noncombative environments, SORE forces may be employed or unavoidably find themselves in combative situations. Offensive operations target an occupying force or established entity threatening US national interests. It may employ guerrilla warfare, subversion, sabotage, intelligence activities, evasion and escape, or other activities of low visibility, covert, or clandestine nature[3] to counter these forces. Defensive or offensive operations may require independent or combined direct combat action by SORE forces. The reader should not construe this paper as an attempt to "freeze" in time the SOF foreign internal defense (FID) and unconventional warfare (UW) missions of today. Rather, the focus must be to ensure the US does not lose these essential capabilities and is caught ill-prepared or off-guard when "endless outbreaks of small wars"[4] indirectly threatening US security become the norm of first- and second-wave nations in 2025. SORE forces will meet these challenges head-on by exploiting the advanced technology of third-wave warfare to improve their ability to operate effectively in the 126 predicted first- and second-wave nations of the twenty-first century.[5] They will not disrupt the evolutionary stage of those countries by introducing third-wave technology before its time but instead will work within the constraints of those countries' capabilities, using third-wave technology only to train, prepare, and protect themselves.

The first step is employing an assessment system to "select" the best recruits for these operations, followed by realistic training and preparation in a virtual reality training center. Second, communications, computer, command, control, and information (C^4I) systems that "blend" into SORE first- and second-wave environments—yet also provide "third-wave" capabilities and interoperability with conventional force systems—are paramount. Third, they must have the know-how and systems to counter threats in these regions and to assist in information warfare (IW) activities. Advances in psychological operations tools and access to "information weapons" will play a key role in SORE countermeasure capabilities and in their collateral role of IW. Lastly, since SORE is performed on a personal level, rather than from a standoff position as envisioned by conventional force or SOF precision strike operations, basic sustainment needs of the individual cannot be overlooked. Simple, portable methods to feed, water, and resupply SORE are needed. Furthermore, lightweight and compact "energy" sources—to ensure power is available for C^4I systems, weapons, and support equipment—must be devised. The details of these tasks and systems, as well as how they will be employed, are the heart of this white paper.

Notes

1. Charles W. Taylor, *Alternative World Scenarios for a New Order of Nations,* Strategic Studies Institute (Carlisle Barracks, Pa.: US Army War College, 1993), 26–28.

2. These were the components of cross-cultural communications identified by USCINCSOC in a briefing to the students of the Air War College on 25 March 1996.

3. Joint Pub 3-05.3, *Joint Special Operations Operational Procedures,* August 1993, II-5.

4. Alvin and Heidi Toffler, *War and Anti-War* (New York: Warner Books, 1993), 103.

5. Taylor, 26–28.

Chapter 1

Introduction

In numerous incidents during the last two decades, the inability of developed countries to protect their interests and even their citizens' lives in the face of low-level threats has been demonstrated time and again.

—Martin van Creveld
The Transformation of War

Although not necessarily a sole superpower in 2025, the US will be a leading third-wave nation.[1] As in the past and present, the US will look to identify a threat to national survival that it can understand and fight on its own terms. This potential peer competitor, like the Germany of the world wars and Soviet Union of the cold war, will, in all probability, be a nation or "entity"[2] that generally thinks, plans, organizes, trains, and equips its forces in ways similar to the US. Justifiably, it will be important to ensure the US is a capable competitor in, if not the leader of, the third-wave world. However, it will be equally important that the US not become so fixated on building an information-based "Maginot Line" that its flanks are left vulnerable to the first- and second-wave threats that Western ethnocentrism or "technocentrism" often misunderstands or overlooks entirely. This is particularly important when one considers 78 percent of the world's population (126 of 147 nations) will live in preindustrial or industrial societies in 2020.[3]

The thesis of this white paper is that in 2025, SORE forces will be the "niche warriors" that provide the capability for the US to successfully engage in the less developed, though no less threatening, worlds of the first and second waves.

Source: *1994 United States Special Operations Forces Posture Statement,* 49.

Figure 1-1. Teaching Rudimentary Skills

Scope

As the thesis indicates, it is not the intention of this white paper to address all aspects of special operations (SO) in 2025. Other valuable SO capabilities such as *Precision Strike* and *Peacespace Dominance* will be addressed in other white papers. The scope of this paper is limited to the *Regional Engagement* capability of SO. The term *regional engagement* refers to the capability to protect and pursue US interests where political and cultural sensitivity, as well as knowledge of first- and second-wave equipment, tactics, procedures, and related support, are critical. It will include potential missions such as sabotage; subversion; guerrilla warfare; evasion and escape; counterinsurgency/secessionist/separatist

operations; and training, advising, and assistance operations.

This is not an attempt to freeze in time what SO foreign internal defense (FID) and unconventional warfare (UW) operations do today. Its basic objectives will be similar. However, Regional Engagement in 2025 will exploit the advanced technology of third-wave warfare to improve its ability to operate in first- and second-wave nations without disrupting the evolutionary process of those nations. In other words, SORE forces will not introduce or train third-wave technology in first- and second-wave nations but rather train and assist those entities in using their own technology. SORE forces will, however, exploit third-wave technology to protect, train, and prepare themselves for operations in these first- and second-wave nations.

Assumptions

The strategic backdrop for this paper is provided in the context of the ***2025*** Alternate Futures. These alternate futures cover a spectrum of possible scenarios and include various assumptions. The following are those assumptions, either synthesized from the alternate futures or developed by this writing team, that are most relevant to this paper's thesis:

- Agrarian, industrial, and information-based societies will exist and coexist in 2025.
- Despite advances in information technology, language and cultural skills will remain critical but elusive for many.
- Employment of humans in hostile, denied, and politically sensitive environments will be required.
- Increased urbanization will require "transparent assimilation" vice physical concealment.[4]
- Although other entities such as large transnational corporations, economic alliances, and nongovernmental organizations will become more significant players in the global community, the nation-state will remain an important actor.

Methodology

This paper is divided into three major sections and two appendices. The thesis, assumptions, and core capability serve as the common thread tying the tasks, force qualities, and underlying technologies to SORE mission needs and core competencies in 2025. The first section (chapters 2 and 3) introduces the reader to SOF core competencies, the core capability of SORE, organization, and our proposed concept of operation (CONOP) to employ this core capability. The second section (chapter 4) addresses and details the critical tasks that enable the CONOP. These enabling tasks are recruitment, assessment, training, observation, communication, decision, countermeasures, and sustainment. Movement is also an important enabling task. However, since movement support for SORE operations will come from non-SOF, host or sponsor, and/or SOF lift platforms (designed for precision strike) and are addressed in the *Airlift, Spacelift,* and *SOF Precision Strike* white papers, we will not address them here. The closing section (chapter 5) provides our conclusions and recommendations for the future. Two appendices support the body of this paper. Appendix A identifies and discusses the force qualities and attributes needed in the recommended systems, as well as the underlying technologies required to create those systems. Appendix B provides a brief definition of those underlying technologies.

Notes

1. Refers to the definitions used by the Tofflers in their books, *The Third Wave* and *War and Anti-War*. The first wave encompasses agrarian-based societies; the second wave, industrial societies; and the third wave, information-based societies. See Alvin and Heidi Toffler, *War and Anti-War* (New York: Warner Books, 1993), 8–9.

2. "Entity" refers to potentially significant nonnational players in the world arena, such as multi- or transnational corporations and other nongovernmental organizations.

3. Charles W. Taylor, *Alternative World Scenarios for a New Order of Nations*, Strategic Studies Institute (Carlisle Barracks, Pa.: US Army War College, 1993), 26–28.

4. For instance, today's UW operations such as evasion and escape focus on avoiding population concentrations. This assumes these missions will only be conducted in isolated areas. Based on this assumption, transparency is achieved by physical concealment. In an urban environment, avoidance of indigenous personnel will be more complex. Accordingly, SORE forces must "blend in" and be capable of handling unanticipated contact.

Chapter 2

Regional Engagement

. . . a bewildering diversity of separatist wars, ethnic and religious violence, coups d'etat, border disputes, civil upheavals, and terrorist attacks, [push] waves of poverty-stricken, war-ridden immigrants (and hordes of drug traffickers as well) cross national boundaries. In the increasingly wired global economy, many of these seemingly small conflicts trigger strong secondary effects in surrounding (and even distant) countries. Thus a "many small wars" scenario is compelling military planners in many armies to look afresh at what they call "special operations" or "special forces"—the niche warriors of tomorrow.

—Alvin and Heidi Toffler
War and Anti-War

Core Capability and Core Competencies

SORE's core capability encompasses two general components: defensive and offensive operations. The defensive objective of SORE is to prevent or free a society from subversion, lawlessness, and/or insurgency. This is primarily accomplished by training, advising, or otherwise assisting host military and paramilitary forces, with the goal of enabling the host to unilaterally assume responsibility for eliminating internal instability.[1]

The offensive objective of SORE is to influence a government or nongovernmental entity whose behavior is contrary to US regional interests. Offensive operations involve a variety of military and paramilitary missions in hostile, denied, or politically sensitive areas. These missions are characterized by long duration, indirect activities including guerrilla warfare, and other offensive, low-visibility, covert, or clandestine operations.[2] SORE forces conduct or train and assist clients in subversion, sabotage, intelligence activities, evasion and escape tactics, and other activities of a covert or clandestine nature.[3] Operations themselves are generally conducted by indigenous forces organized, trained, equipped, supported, and directed in varying degrees by SORE forces.[4]

The SORE core capability and special operations force (SOF) core competencies are closely related. Although the targets and focus of regional engagement may vary over time, the five core competencies are timeless. SOF must (1) be skilled in the use of unconventional equipment and tactics; (2) excel in politically sensitive environments; (3) employ unorthodox approaches; (4) exploit limited opportunities; and finally (5) use and produce specialized intelligence. The following paragraphs further define the core competencies and link them to SORE. Specifically, SORE forces must be skilled in the use of unconventional equipment and tactics.

> The unusual demands of a SO mission define the training and equipment required. Often, accomplishing the SO mission calls for a unique mixture of specialized skills and equipment that may be outside the capabilities of conventional forces.[5]

In 2025, this will be manifested in two ways for SORE operations. First, SORE must possess cross-cultural skills. In other words, they must be regionally focused, skilled in foreign language, and culturally attuned. Second, the force must be skilled in the employment of equipment, tactics, procedures, and support functions

associated with first- and second-wave societies and warfare.

Given the nature of their projected employment, they must excel in politically sensitive environments and operations.

> Virtually every aspect of a SO mission is constrained by the politically sensitive context in which it is conducted. For instance, the cultural mores of a country may dictate a low-profile operation, while in another situation, larger political considerations may require a visible presence in an advisory capacity. [SO] are marked by the need for political sensitivity and require patient, long-term commitments to achieve national objectives.[6]

Patient and *long-term* are the key adjectives of this core competency. These terms neither characterize the nature of conventional force employment nor the American public's attitude about such employment. SORE operations cultivate the relationships and presence necessary to conduct missions where our interests are at stake in politically or economically sensitive areas, not otherwise accessible to conventional (third-wave) forces, yet with significant economies of force. SORE operations also provide the flexibility of using SOF visibly when a high-profile US presence is desired or covertly/clandestinely when no US signature is required, but human presence is necessary.

To meet these diverse profile employment efforts, SORE forces must employ unorthodox approaches.

> SO missions do not negate the traditional principles of war. Rather, a different emphasis is placed on their combination or relative importance. In a SO mission, surprise achieved through speed, stealth, audacity, deception, and new tactics or techniques can be far more effective and efficient than a conventional force using traditional tactics based on massed firepower and tactical maneuvers.[7]

In 2025, conventional, third-wave operations and tactics may be characterized by very precise munitions delivered from unmanned platforms or the manipulation of data from a work station far removed from the intended target. In such a world, the ability to infiltrate a SOF team and remain long enough to build a relationship of trust with indigenous personnel will certainly be considered unorthodox, yet remain critically important.

These unorthodox, critical approaches will require strict windows of availability and criteria to meet successful fruition. Specifically, SORE forces must be capable of exploiting limited opportunities.

> Some SO missions . . . must capture the appropriate moment for complete success. Tactical advantage may be limited and fleeting. Repeat opportunities are unlikely, and failures will be politically and militarily costly.[8]

Although more characteristic of SOF *Precision Strike* missions, SORE operations, by exploiting the worldwide presence of deployed forces in politically sensitive areas, may provide information or be used to conduct missions where a narrow window of opportunity exists. This will be true for both low-visibility and high-visibility missions.

Again, relative to the exploitation role of SORE forces in these visibility missions and all other tasks, SORE members will use and produce specialized intelligence.

> SO missions are intelligence-driven and intelligence-dependent. They require immediate and continuous access to information from traditional as well as nontraditional sources. SO generally rely on formal intelligence structures, but, for certain sensitive missions, tactical and operational information must be developed using SOF assets such as advance or reconnaissance forces. Moreover, SOF need detailed national and theater intelligence products at the tactical level of execution, often in near-real-time.[9]

SORE forces will be an excellent, nontraditional source of information valuable to political, diplomatic, economic, and military decision makers. Long-term relationships developed with indigenous personnel and/or host governments and military officials may allow the gathering of information not otherwise possible through traditional military, diplomatic, or economic contacts.

Employment Opportunity

The opportunity to employ this SORE core capability will be ripe given any of the

six ***2025*** Alternate Futures.[10] All include the possibility for instability associated with lawlessness, subversion, insurgency, separatism, secessionism and states or other entities that sponsor or conduct terrorism and other destabilizing activities. Clients may include host nations or virtually any legitimate international organization whose maintenance of stability in a given region is in the interest of the US (e.g., multi-/transnational corporations, nongovernmental organizations, and regional alliances or coalitions). SORE operations may also be targeted *against* such entities should they conduct or sponsor activities that promote instability or are counter to US interests. Opportunities for miscalculation also exist. As noted in the following, this is particularly true regarding language and cultural skills.

> The relevance of [training] programs . . . depends heavily on requirements that the US intelligence community cannot always predict. Egypt and Syria emerged as the most important Arabic dialects after the Arab-Israeli War of 1967. As a direct result of that decision, only 16 Arab linguists on active duty (less than one percent) had studied Iraqi before Saddam Hussein invaded Kuwait. No one predicted large-scale SOF employment in Kurdistan or Somalia, where Operations PROVIDE COMFORT and RESTORE HOPE took place. The maintenance of language skills is just as essential as initial learning but, for most linguists, peak proficiency occurs the day they receive their diploma.[11]

The above example provides for a positive opportunity. It illustrates how third-wave information technology can be exploited to improve our ability to engage in first- and second-wave warfare. For instance, the capability to transform information into knowledge and, ultimately, into wisdom will contribute to our ability to identify future flash points and subsequently adjust our language training. Similarly, improved technology such as the introduction of more sophisticated translating devices (although no substitute for face-to-face conversation in the spoken language)[12] and other learning enhancement devices and techniques will likely improve comprehension and retention.

Organization

It is not the intention of this white paper to become immersed in the intricacies of organizational structure, service component responsibility, or any other controversial organizational issues associated with details and minutiae. Rather, the purpose is to identify and discuss the important characteristics of any SORE organization—be it a service or joint organization.

Regional Orientation

> Americans often become "bulls in china shops" . . . The "American way" of dealing with problems sometimes fails in the international milieu. It is particularly important for American leaders . . . to be sensitive to national concerns and to listen carefully to . . . other nations.
>
> —Perry M. Smith
> *Taking Charge, A Practical Guide for Leaders*

Source: *1994 United States Special Operations Forces Posture Statement*, 17.

Figure 2-1. SORE Forces Interact with Indigenous Personnel

Gen Perry Smith's warning further underscores the importance of robust SORE forces possessing the components of an effective cross-cultural communications capability—foreign language proficiency, cultural and area awareness, nonverbal communications, and interpersonal skills.[13] An organizational structure, based on regional orientation, is critical to ensuring SORE forces maintain this vital cross-cultural

capability. In a fiscally unconstrained military, areas of regional responsibility could be made smaller and more numerous to limit the diversity of language, cultural, and military capability within any one area. Such an arrangement would allow for highly focused training and proficiency in language skills, weapons, and tactics. In a technologically unconstrained world in which a transparent language translation capability, "gift of tongues," is available, division of regional responsibility would be less constrained or perhaps not necessary. However, based on the alternate futures and our developed assumptions, it is not likely such a favorable environment, either fiscally or technologically, will exist in 2025. With this premise in mind, figure 2-2 illustrates a notional division of responsibility that seeks some balance between diversity within a region and force structure size limitations. Since SORE operations are focused on first- and second-wave areas; North America (less Mexico), Western Europe, Japan, Australia, and New Zealand are not included in the regional coverage scheme. The specific boundaries shown, although not entirely unrealistic possibilities, are for illustrative purposes only.

Force Size

The nature of the SORE mission will determine the size of the force. Offensive SORE missions such as sabotage or evasion and escape may require less than 10 people with little equipment. Conversely, a defensive SORE mission to train, advise, and assist a fledgling air force in air-to-ground tactics and procedures, in maintenance inspection methods, spare parts management, and weather observance and forecasting, may require a significantly larger team, in a more visible role. Nonetheless, either can be conducted more unobtrusively than large, conventional operations whose actions may be followed closely by the international media.

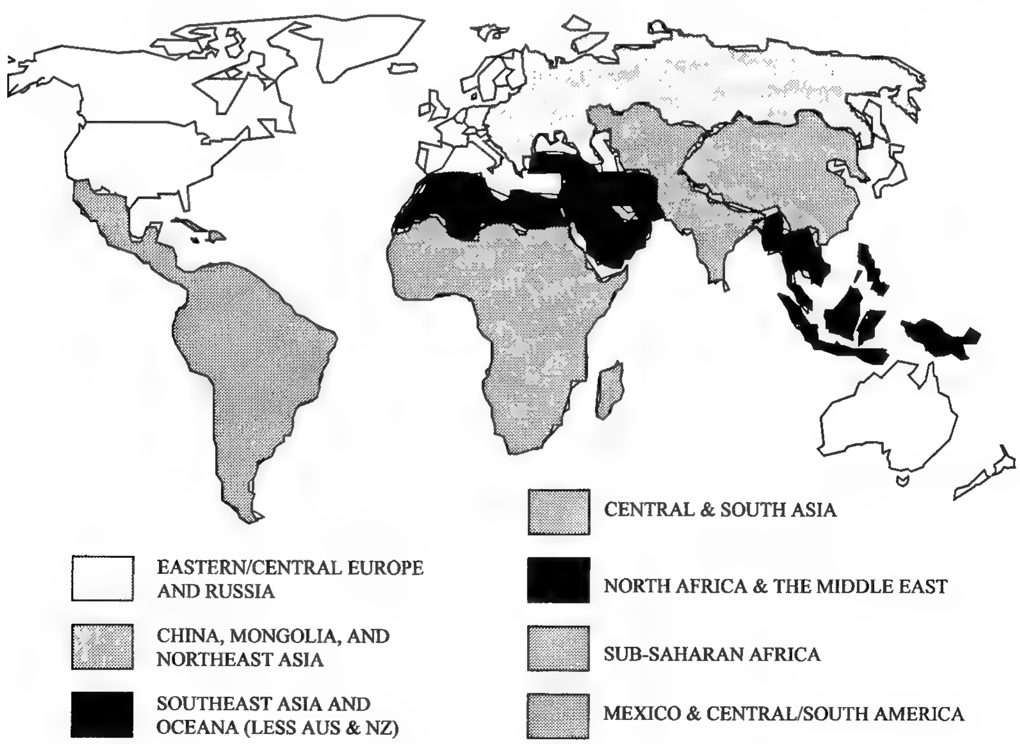


Figure 2-2. Notional SORE Areas of Responsibility

Decentralized Control and Execution

Greater battlefield awareness coupled with improved C^4I will require an individual who can make rapid and correct decisions . . . these changes imply a dramatically flattened command structure staffed by an extremely high caliber of individual at every level.

—*Warfighting Vision 2010, A Framework for Change*, 1 August 1995

Another important attribute of SORE organization will be a "flat" structure that emphasizes decentralized control and execution. The continuous, long-term, low-visibility, and cross-cultural nature of SORE operations demand a force that can accomplish the mission with little more than clear articulation of the desired end state and associated rules of engagement (ROE). Within these broad constraints, the SORE operator can be trusted to rely on his/her extensive training to determine the best means of accomplishing the mission (in accordance with the ROE).

Focus of Expertise

The final attribute of a SORE organization is the focus of its expertise. The aviation training mission provides a good example. The ultimate objective of SORE defensive operations is to empower the client to protect itself and maintain stability using organic equipment, weapons, and, most importantly, personnel. In terms of aviation, it is not the primary objective to teach the rudiments of initial flying qualification or "wrench turning." It is assumed the client already has the capability to provide these basic skills. The focus of SORE operations is to improve the client's tactics and weapons employment, which may include training and procedures associated with support functions such as supply, maintenance, and weather. This focus has force structure implications as well. Since pilots will fly in an observer role, it is only necessary for SORE operators to be familiar with the overall characteristics of aircraft flown in the regional area of responsibility. It is not necessary for them to be qualified in all aircraft in the region. Subsequently, SORE aviation units need only possess aircraft that closely resemble the characteristics of aviation platforms in that geographic area. This capability may be accommodated through leasing arrangements that allow the unit to change its aircraft inventory to reflect regional changes on a near-real-time basis. This approach is far less costly and time consuming than the traditional research, development, acquisition and life cycle maintenance associated with traditional military aircraft inventories.

This flexible, regionally focused organizational structure optimizes the core competencies and capability discussed in this chapter. Together, they provide the foundation for successfully implementing the CONOPs in the next chapter.

Notes

1. Joint Pub 3-05, *Doctrine for Joint Special Operations*, October 1992, II-8.
2. The terms *covert* and *clandestine* are often confused. Doctrinally, and for the purpose of this paper, they are defined as follows. A *clandestine* operation places emphasis on the *concealment of the operation* itself. A *covert* operation places emphasis on the *concealment of the identity of the sponsor*. In special operations, an activity may be both covert and clandestine and may focus equally on operational considerations and intelligence-related activities. (See Joint Pub 1-02 and Joint Pub 3-05.)
3. Joint Pub 3-05.3, *Joint Special Operations Operational Procedures*, August 1993, II-1.
4. Joint Pub 1, *Joint Warfare of the United States Armed Forces*, January 1995, I-X.
5. United States Special Operations Command, *United States Special Operations Forces Posture Statement*, 1994, 3.
6. Ibid.
7. Ibid., 4.
8. Ibid.
9. Ibid.
10. Refer to the *Alternate Futures* white paper for specific definitions.
11. John Collins, CRS Report for Congress, *Special Operations Forces, An Assessment 1986–1993*, 30 July 1993, 1991.
12. This assertion is further addressed under the "Advantages of SORE" section of chapter 3, Concept of Operations.
13. These were the components of cross-cultural communications identified by USCINCSOC in a briefing to the Air War College on 25 March 1996.

Chapter 3

Concept of Operations (CONOPS)

The Americans neglected to study history's many examples of supposedly outmatched combatants prevailing over better-equipped rivals. And they took it for granted that their potential adversaries would accept the American interpretation of the "revolution." But America's most likely opponents were invariably unlike America and thus not beholden to the American interpretation.

—Charles J. Dunlap, Jr.

The CONOPS for SORE in 2025 involves a broadening and enhancement of current foreign internal defense and unconventional warfare capabilities. This is particularly true for the aviation or specialized airpower component of SORE. Like the capability it employs, the CONOPS has both a defensive and offensive component (see fig. 3-1).

Defensive SORE

Given the diversity of the SORE missions within the "peaceful" realms, the defensive component can be further divided into combat and noncombat operations. Both focus on developing the indigenous leaders, organizations, and individual skills of host nations, or other entities determined to be legitimate and whose viability is considered to be in the interest of the US. In other words, these defensive SORE operations are centered on training, advising, and assisting. Ideally, potential customers are identified before they face an organized, destabilizing threat. In such cases, SORE operations would be conducted in a controlled environment that presents little threat of subjecting the

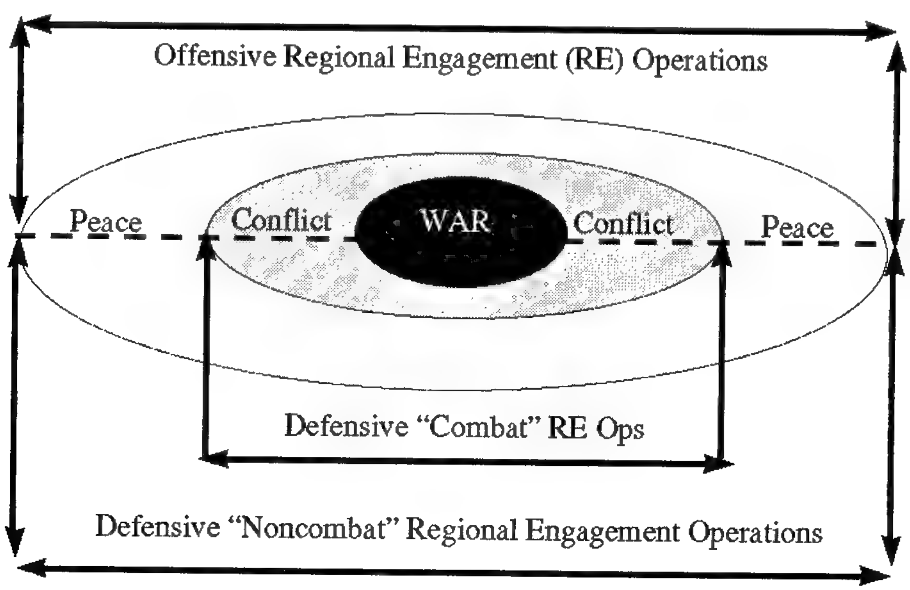


Figure 3-1. The Realm of Special Operations Regional Engagement

team to hostile action. However, "when subversion, lawlessness, or insurgency [separatism, or secessionist activities] threaten a friendly nation's stability, the NCA may direct US forces to provide support to friendly nation's counterinsurgency [et al.] efforts. This support is distinct from . . . training or advisory assistance . . . because it involves the operational commitment of US forces."[1] It is entirely likely that SORE operations may begin in a noncombat environment and transition to a combat environment.

An example of defensive operations may involve the employment of a SORE aviation team into a developing, second-wave nation. In such a case the team might assist the fledgling air force in developing doctrine, tactics, and procedures for conducting close air support of ground forces or combat search and rescue; a logistical system to support flying operations; and, perhaps, a limited weather observation and forecasting capability. Should the competency of this notional air force be so rudimentary, the NCA may be compelled to direct SORE forces to actually fly combat missions as part of the host nation's aircrews. Such a decision clearly raises the consequence of failure. However, due to the possibility of a rapid transition from noncombat to combat, SORE forces must always be prepared for such an eventuality.

Offensive SORE

The offensive component of SORE "includes guerrilla warfare, subversion, sabotage, intelligence activities, evasion and escape, and other activities of a low visibility, covert, or clandestine nature."[2] The core of offensive SORE operations, similar to the defensive component, is training, advising, and assisting. However, there are two essential differences. The first is the nature of the target. In offensive operations, SORE activities are directed against an established entity or "occupying" force. The second follows from the political sensitivity of the first. The operation will almost always be conducted in a covert or clandestine manner to effectively mask US involvement. This last consideration may lead to the requirement to use sophisticated systems to infiltrate, exfiltrate, sustain, and communicate in a clandestine or covert manner. The challenge will be to exploit third-wave technology such that it will be transparent in a first- or second-wave environment.

An example of offensive SORE operations in the context of the "Zaibatsu" alternate future may involve the infiltration of a SORE team into a region dominated by a multi- or transnational corporation where vital American interests are at stake.[3] Such a mission may be characterized by training, advising, and assisting indigenous personnel in harassment activities. Such an operation might also facilitate or complement a SOF precision strike mission aimed at disrupting information systems.

Advantages of SORE

The advantages of possessing a core capability to conduct SORE operations in 2025 are several fold. First, since SORE operations are focused on first- and second-wave entities, emphasis will be on weapons, tactics, procedures, and support infrastructure considered crude or primitive, both today and 30 years hence (fig. 3-2). Conventional forces of 2025 will not possess these cruder weapons, and subsequently, have no expertise in their employment.

Second, even if technology is available for universal or programmable language translators, imagine how intimidating or socially offensive the use of such devices might be to a non-Western and/or lesser-developed people. Unless such translation devices can be made transparent to the receiver, they will be inadequate as a replacement for the language-skilled, culturally attuned individual. The following example illustrates this point.

> In Uganda last year during the efforts to assist the refugees from Rwanda, an Army Special Forces captain was tasked to introduce American aid representatives to the President of Uganda.

Source: USSOCOM Pub 1, *Special Operations in Peace and War*, 2–15.

Figure 3-2. SORE Forces Training in the First and Second Waves

> The captain started off the conversation, introducing himself and greeting the president in the President's own language. This impressed the President greatly and smoothed the introduction of much more difficult topics and discussions. The captain's [language and cultural] training and previous deployments had allowed him to . . . make the telling first impression.[4]

Third, interpersonal relationships cultivated during SORE operations "strengthen ties with the host nation [or other entity] while building future 'contacts' that may not otherwise be available through traditional [or conventional] military or diplomatic channels."[5] Fourth, SORE operations are preventive in nature and therefore result in significant economies of scale. Early engagement of small, unobtrusive SORE teams in a variety of locations throughout the globe provide the ability to influence events before they become media spectacles and take on a life of their own. These teams also provide a source of intelligence that can be placed in a cultural or societal context not possible with other sources.

Having described the offensive and defensive components, as well as the advantages of the CONOPS, this paper now turns to its enabling tasks. In the chapter that follows, these tasks and their attributes are addressed and evaluated in detail.

Notes

1. Joint Pub 3-05.3, *Joint Special Operations Operational Procedures*, August 1993, II-5.
2. Ibid., II-1.
3. Refer to *Alternate Futures* ***2025*** white paper.
4. USCINCSOC Congressional Testimony, 27 March 1995.
5. ***2025*** Concept, no. 900772, "Aviation Foreign Internal Defense," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996), 1.

Chapter 4

Enabling Tasks

As scarce resources are allocated and the highly visible . . . systems receive the most attention, it is the grunt—often equipped much as his grandfather was—that is most often called upon to implement foreign policy . . . Many situations . . . will still require . . . the ability to interact with local populations, and the ability to make human "in the loop" decisions.

—*Warfighting Vision 2010, A Framework for Change,* 1 August 1995

Based on the concept of operations for SORE, very specific and defined enabling tasks emerge. Sequentially, the tasks of recruit, assess, train, observe, communicate, decide, counter, and sustain follow and are measured. In the tables throughout this chapter, the terms *critical, desired,* or *ideal* refer to the attribute's level of need for each task. A critical attribute is required to accomplish the task. A desired attribute allows for a reasonable expectation of enhancement that is within fiscal and technological possibility. In other words, a desired attribute may make task accomplishment or system outcome faster, more precise, or lighter weight, but the mission can still be accomplished without it in 2025. Lastly, an ideal attribute enhances task accomplishment and ultimately mission execution, yet may push fiscal and technological limits.

Recruit, Assess, and Train

My first plea is for the frontiers—not the mainstream. The mainstream, by definition, will have enough volunteers and preferences to garner the attention it needs to see us through the necessary doctrinal evolution. But what of the lonely, dangerous frontiers, with all of their uncertainties and risks? Will we have enough volunteers? Will those who volunteer have the wit, courage, and stamina that frontiers seem always to demand of pioneers? I hope that the frontiers of air and space doctrine will beckon those airmen who have the potential to be doctrinal pioneers.

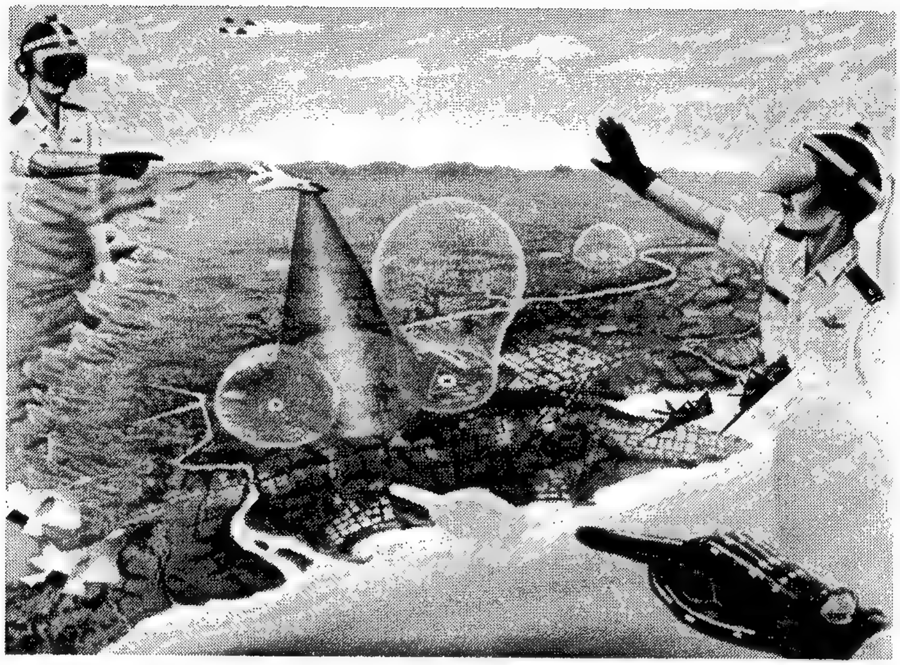
—Carl H. Builder

Given that SORE operations in 2025 may occur with limited opportunity to prepare are politically sensitive and will occur in permissive, hostile and/or denied environments, selective recruitment, detailed and thorough training, coupled with continuous mission rehearsal and assessment, will be critical. The use of specialized equipment and unique skills dictate the need for an ongoing, comprehensive recruitment, training, and assessment program. To this end, SORE forces will undoubtedly take advantage of developing technologies. As mentioned previously, their efforts may include direct support of first- or second-wave military or fielded forces, multinational corporations, or other governmental agencies.

If you tell me, I'll listen.
If you show me, I'll see.
If I experience it, I'll learn.

—Lao Tze, 430 BC

To effectively meet these train-to-task missions, both on a continuing basis and for initial selective trimming of SORE candidates, development and use of virtual reality centers or the "holo-deck" type arenas, currently envisioned in the *Star Trek* TV series, should be pursued. These virtual reality centers would allow SORE forces to totally "immerse themselves" in the pending or projected mission(s) (ideally to include anticipated "environmental influences"



Source: http://www.afit.af.mil/schools/PA/gall3.htm. Artwork courtesy of Gene Lehman.

Figure 4-1. Illustrated "Virtual Reality" Center Concept to Provide Experience

[i.e., rain, snow, mud, and cold to be encountered]). For those previously qualified, the centers would provide ongoing refresher or reorientation training. For new accessions or potential candidates, the center would serve as a proving ground to determine the acceptability of an untested recruit.

Further, potentially every member involved in a particular mission or deployment could rehearse his part with all the reality of executing the mission void of the potential ramifications of mistake in a sensitive environment. Mission rehearsal or selection parameters could be repeatedly played out with multiple contingencies and backup scenarios to force reactive and proactive player responses. The SORE virtual reality training centers could be linked with other similar centers allowing all participants, military and civilian, who are not geographically collocated to interact, train, and rehearse as a single entity—as if actually accomplishing assigned tasks and responsibilities well in advance of true debarkation. Additionally, the centers should be linked to "real-time" national assets—intelligence, information and data collection, and battle management systems—to afford the injection of real-time conditions into mission training and rehearsal.

The SORE virtual reality training centers would allow mission particulars such as cultural awareness and immersion to include language skills to be "experienced" first-hand. Similarly, operating with dangerous materials, highly specialized or first-wave one-of-a-kind equipment, and unique tactics could be repeatedly practiced or rehearsed, improving the quality of training and likelihood of mission success. The virtual reality training centers would be equally useful as proving grounds for evaluating potential SORE candidates.

Accordingly, SORE recruitment, assessment, and training regimens and the system descriptions to support those regimens must be highlighted for operations in 2025. Initially, given the nature of SORE tasks, the potential conditions and environments in which those conditions will occur and the

realistic assumption that SORE force structure will consist of a small number of selectively trained and experienced warriors, picking the "right troop" in 2025 could prove to be the cognizant driver in the accession process.

To illustrate the importance of selecting the highest caliber forces, USCINCSOC's testimony to Congress in March 1995 provides a concise vision of what those selection demands could hold for SORE forces of the future.

> It . . . requires a particularly mature, independent, and self-starting individual who can operate in small groups, often in harsh environmental conditions. Finding these kinds of individuals requires a special selection and assessment process that can gauge a person's suitability to these kinds of tasks.[1]

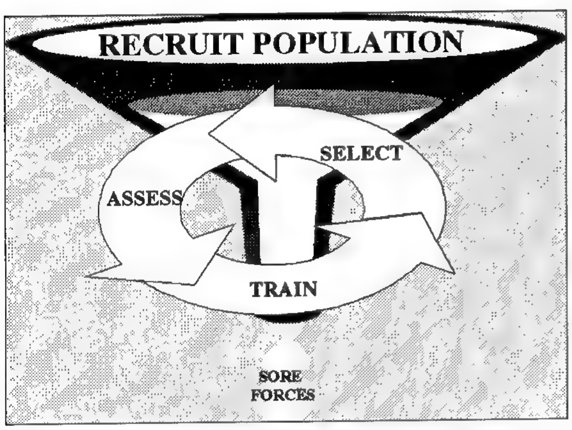


Figure 4-2. Recruit, Assess, and Train Selection Cycle

As mentioned, this "mature" population must come from the mainstream—either conventional forces or general population. Accordingly, the "Recruit, Assess, and Train Cycle" used to facilitate SORE force acquisition must be attuned to the pool of candidates available and weighted against the needs of protracted mission accomplishment. In that light, force designers must begin with the basics and construct a viable marketing program to attract potential SORE candidates. After an "acceptable" pool of candidates is identified, a vigorous assessment cycle must commence to determine which potential candidate(s) will "make the cut" for qualification training. Figure 4-2 graphically illustrates the conceptual framework for this initial recruitment and selection cycle. As noted, the recruited population may be large. After a series of "selective" psychological and physical screening tests, the pool will dwindle to reasonable proportions, similar to the manner in which NASA and the Navy screen their astronaut and SEAL candidates respectively.

While the recommendations for enhancing the collective recruit, assess, and train regimens for SORE forces follow, the concept of selective retention must be assumed.[2] Considering the enduring nature of our core competencies, the same "selective" process of today must occur in 30 years, yet must be replete with the technological and medical advances anticipated. A grounded commonality remains, the process is continuous. As candidates enter the recruit funnel, the continual selection, assessment, and training regimen must be used time and again. The outcome of the cycle will result in culturally attuned, physically and mentally prepared SORE forces capable of implementing and sustaining the rigorous demands of the SORE CONOPS. At any point within this cycle, a recruit will be dismissed or returned to conventional forces since SORE force employment and application is a "high-risk-of-failure" proposition.

Table 1 provides the attributes needed and desired in the initial selection/screening process and the follow-on assessment and training requirements. While these parameters will serve to initially select, continually assess, and later prepare SORE forces for specific areas of performance, the essence remains to develop an organic approach to refining the initial selection process.

In that vein, genetic engineering, testing, and selection parameters may prove to be an early discriminator to achieve this goal.[3] Similarly, during the initial process, advance testing should be adopted to apprise an applicant's potential to learn

Table 1

Recruit, Assess, and Train Attributes

ATTRIBUTE	RECRUIT	ASSESS	TRAIN
Cultural/Political Sensitivity	*Desired	Desired	Critical
Regional Orientation	Ideal	Desired	Critical
Language Proficiency	Desired	Critical	Critical
Negotiation Skills	Desired	Desired	Critical
Psychological Profile	Critical	Ideal	Ideal
Cognitive Learning Ability	Desired	Ideal	Ideal
Physical Attribute/Ethnicity	Desired	Desired	Desired
Adaptability	N/A	Critical	Critical
Interactive (Realistic)	N/A	Desired	Critical
Individually Tailored	N/A	Ideal	Ideal
Portability	N/A	Desired	Desired
Interoperability	N/A	Ideal	Critical

**Critical, desired,* and *ideal* refer to "level of need" for task accomplishment.

language based on brain hemisphere dominance, profile his/her psychological state to determine historical nurturing, and IQ testing to rate cognitive learning ability. Further, future mission requirements will dictate that physical attributes of the candidate(s) be considered in building the force structure versus simply filling projected losses. To restate, initial selection procedures will be critical to effectively field the highest caliber forces to achieve specialized and changing SORE mission objectives. Given the nature of the SORE mission and the potential expense associated with its follow-on training, mistakes must be kept to a minimum or be systematically revealed at any point in the selection and/or assessment process. Ultimately, the training of selected individuals will refine and result in cognizant members capable of effectively operating as SORE employed forces.

To meld the selection and training profiles and further qualify this process, an essential element will be to speed the learning process of the people selected and being trained within the virtual system. Some innovations and ideas relevant to this enhanced ability may range from artificially intelligent word processing,[4] to selective knowledge pills[5] ingested as situations dictate, to accommodate the increased need to absorb magnitudes of data over extended periods of time or for short durations. Overall, these concepts may provide the key links for allowing our selected SORE forces to receive and process the massive output of the envisioned Virtual Reality Center. Again, USCINCSOC's testimony appropriately addresses the criticality of the collective tasks:

> Units that conduct these operations invest a great deal of time and energy in language proficiency, cultural awareness, and regional orientation. It often takes years of study, in the actual area of operations, to develop the kind of understanding required to work with forces where the SOF operator has no command authority but must accomplish the mission through cooperation and mutual understanding. This must be followed by a training program that teaches not only the language and regional specifics, but also how to deal with and operate in unusual situations where there usually are no doctrine or guidelines and they have no authority to issue orders but must use persuasion to solve a myriad of challenges they confront.[6]

Collectively, recruitment, assessment, and training will be critical to the effective fielding of SORE forces in 2025. Without these building blocks of successful selection and preparation, the end game of their actions cannot be assured or predicted with any certainty. However, by applying specific standards to these criteria, we will dramatically increase the probability of success by fielding a select group of brilliant warriors, selected, educated, trained, and employed in diverse regions of the world. As noted by Lt Gen Jay W. Kelley in his article addressing the brilliant warrior concept as applied to professional military education—"Brilliant warriors must be critical thinkers."[7] The rigorous recruit, select, and train regimens described in this chapter will help produce the "brilliant warriors" of 2025.

Observe, Communicate, and Decide

Advanced materials and electronic developments will lead to enhanced SOF communications capabilities. These [will] include features such as miniaturized command, control, and communication functions as well as embedded artificial intelligence for situational decision making. . . . To keep pace with mission requirements, SOF will require enhanced, next-generation communications equipment.

—*United States Special Operations Forces Posture Statement*, 1994

Three enabling tasks of SORE's core capability—observation, communication, and decision—have been grouped together because they are an inextricably linked process. Observing data, without communicating it, is of little value. Even if the ability to observe is enhanced and methods of transmitting data are improved, there is no value added unless there is a means of turning that information into knowledge useful to the decision maker. Therefore, it would be a mistake to look at these tasks individually, since the process must facilitate all three.

Brig Gen William E. Harmon, USA, program manager for the Joint Tactical Fusion Program wrote, "The most sophisticated intelligence collection in the world is worthless if the information it provides does not reach the commander in a timely manner."[8] The authors of *New World Vistas: Air and Space Power for the 21st Century* also agree. They assert, "The power of the new information systems will lie in their ability to correlate data automatically and rapidly from many sources to form a complete picture of the operational area, whether it be a battlefield or the site of a mobility operation."[9] Restated, the ability to collect, fuse, and process data into a usable form and then ship the information to the decision maker on demand is crucial. Whether the process is "third wave" as discussed by *New World Vistas*, or crude "first- or second-wave" where the process may be as simple as "seeing" with one's own eyes, "telling" someone what you saw, "discussing" it, and then acting—the need for effective interweaving of these three tasks remains high. For familiarity, the term *C⁴I* (communications, computers, command, control, and intelligence) is used to refer to the "observe-communicate-decide" process—not a technological system, but rather a process.

Table 2 lists the 12 attributes imperative to the observe-communicate-decide process. The first seven—interoperability, divergence or fusion, portability, transparency, face-to-face contact, security, and resolution—are critical to SO regional engagement operations and are captured in four overriding requirements. These requirements are discussed at length in this section. The remaining five attributes are desired, not critical, and are briefly discussed.

The *four overriding requirements* needed for successful employment of SORE's observe-communicate-decide task in 2025 are (1) interoperability and fusion with third-wave C^4I systems with appropriate range, speed, and accuracy qualities, as well as a divergent detection and resolution capability; (2) portable field equipment that is lightweight, secure, and survivable; (3) C^4I equipment that "blends" into first- and second-wave nations—either using twentieth-century

Table 2

Observe, Communicate, and Decide Attributes

ATTRIBUTE	OBSERVE	COMMUNICATE	DECIDE
Interoperability	*Critical	Critical	Critical
Divergent and/or Fused	Critical	Critical	N/A
Portability	Critical	Critical	Desired
Transparency	Critical	Critical	Critical
Face-to-Face Contact	Critical	Critical	Critical
Security	Critical	Critical	Critical
Resolution	Critical	N/A	N/A
Range (global/local)	Desired	Desired	Desired
Speed (near real time)	Desired	Critical	Desired
Capacity (giga-terabits/sec)	Desired	Critical	Desired
Survivability	Desired	Desired	N/A
Accuracy	Desired	Desired	Desired

**Critical, desired,* and *N/A* refer to "level of need" for task accomplishment.

equipment or camouflaged, customized equipment that is transparent in first- and second-wave worlds; and (4) face-to-face communications to keep the "human in the loop." Each requirement is impacted by various aspects related to the technology already available in the conventional forces or by the environment in which it will be employed. These aspects are addressed along with each requirement in the following paragraphs.

First, we must recognize most of SORE's third-wave C^4I support will come from non-SOF resources. The primary third-wave support will be interoperable, robust networks that provide an integrated C^4I network where image, voice, and digital data are fused for transmission and receipt. An underlying concern with conventional fused systems is that "fusion" does not simply provide an "average of two data sets," but rather a divergent detection and resolution capability necessary to support the precise nature of SOF targeting requirements. Furthermore, fusion may be difficult to attain. As *New World Vistas* study stresses ". . . robust interpretations of sensor data are hard to develop from mathematical considerations alone . . ." and commonsense reasoning about the process of fusion must be understood and automated.[10] With or without fusion, the network must also be near real time, secure, survivable, and provide redundant transmission paths. These capabilities are not only needed for SORE but also for the conventional forces.

Information obtained from conventional C^4I systems and divergent detection and resolution sources will be used in defensive SORE operations where the mission is focused on assisting and training sponsor forces in a noncombative environment. These sources will provide a secure, reliable C^4I link "back home" and simultaneously provide interoperability and intelligence sharing with coalition forces, host nations, or clients. As noted in Joint Pub 3-07, "US intelligence sharing ranges from strategic analysis to current intelligence summaries and situation reporting for tactical operations. An adequate intelligence collection and dissemination capability is

often one of the weakest links in a host nation's military capability."[11] However, we must be careful about what third-wave knowledge we share and how we share it. We do not want to provide "intelligence" obtained from third-wave sources or to provide the host a direct "link" to our systems unless we plan to leave it behind for the host's future use. Otherwise, when the forces depart, the host will be at a loss.

This concept is best explained by using an example from our CONOPS where US SORE forces are training a host and then are tasked to join the flying crews of sponsor nations when the environment shifts into a combative mode. It would be tempting to offer third-wave intelligence sources to pinpoint enemy actions and to assist the sponsor in developing an operations plan, just to protect our own SORE pilots. However, this action risks leaving the host more vulnerable than when we arrived. A better approach is for SORE forces to take advantage of their "link" to intelligence systems during the noncombative phase, to keep in tune with changing events in the area and to formulate the best method to optimize the host's existing forces and resources to locate and eliminate the threat. For example, they might help the host set up a human intelligence (HUMINT) network or retrofit an existing aircraft with reconnaissance gear to gauge the nature of the impending threat. Teaching the host how to use their own resources versus "plugging" them into ours is much more beneficial to their future development.

Another key use of these same third-wave systems is predicting and dealing with the effects of urbanization. Population trends indicate that by 2010, 50 to 65 percent of the world's population will live in urban areas.[12] We have already seen the impact of urbanization on US operations in Somalia, Haiti, and Bosnia where starvation, disease, pollution, and mass migration are staggering. The United States' "capability to operate and conduct military operations in built-up areas and to achieve military objectives with minimum casualties and collateral damage requires more precise weapons, surveillance, sensing, target detection, and situational awareness enhancements."[13] Payback for developing divergent detection and resolution will be realized in this case, since "precision" will be critical.

The future holds great promise for systems that collect, fuse, and distribute information. The most likely candidates are a Global Surveillance, Reconnaissance, and Targeting System (GSRT),[14] an ultraprecise, jam-resistant global positioning system (GPS),[15] and worldwide surveillance, collection, and reconnaissance done from commercial, possibly international conglomerate platforms producing high-resolution mapping and worldwide weather monitoring.[16] Again, the key is to provide a "fusion" capability that does not simply produce an "average of two data sets," but rather a divergent detection and resolution capability necessary to support SOF precision identification and targeting requirements, particularly offensive SORE operations.

Similarly, there are many possibilities for improved communications networks in the future. The three most likely successors, Distributed Satellite Systems, Fiber and Satellite Networks, and direct link between satellite and aircraft, are described in *New World Vistas: Air and Space Power for the 21st Century.*[17] Since these systems are addressed in the *Information Operations, Counter Information,* and *S & R Information Operations* white papers, we will describe them only briefly in the Systems and Underlying Technologies appendices. However, SORE "packaging" of these third-wave C^4I systems for use in first- and second-wave nations may differ from conventional packaging. This "unique" packaging will be addressed in the third requirement.

The second requirement deals with the C^4I systems necessary for covert or clandestine operations normally associated with offensive SORE.

> [These types of SOF] missions are intelligence-driven and intelligence-dependent. They require immediate and continuous access to information from traditional as well as nontraditional sources. SO generally rely on formal intelligence structures, but, for certain, sensitive missions, tactical and operational information must be developed using SOF assets such as advanced reconnaissance forces.[18]

> Quite simply, SOF operations will require the full array of intelligence products available to conventional forces, such as indications and warning data, orders of battle, threat tactics, weapon systems characteristics and capabilities, communications, environmental, and maritime factors.[19]

SORE forces will need lightweight, mobile, secure, and survivable equipment that works well in harsh, austere environments, that ensures low visibility for covert or clandestine operations, and that inherently guarantees synchronization and security of small teams fighting subversion, lawlessness, insurgency, and terrorism. The same equipment will be needed for teams that must "up close and personally" verify information on enemy capabilities, intentions, and activities that are unverifiable through conventional surveillance and intelligence means. This equipment must have the range and capacity for teams to communicate securely with command and control centers, with each other, with intelligence sources, and/or directly to weapons delivery systems.

A miniature C^4I unit, constructed of micromechanical devices where a "single chip" is the entire system, could be embedded in a helmet, on a sleeve, or in a wristband. The system could be voice, gesture, or thought controlled as deemed plausible in *New World Vistas: Air and Space Power for the 21st Century's*[20] concept of Human/Machine System Fusion.[21] The All Seeing Warrior concept[22] or the Tactical Information Display Helmet[23] are both excellent examples. Another possibility is to build very small aperture antennas (VSAT) into the receiver systems which are capable of transmitting video and sophisticated computer-generated data around the world.[24] These VSATs could be mounted on or embedded in a C^4I helmet, wristband, or any other "handy" device. In each case, either non-SOF or specialized SOF C^4I systems, with capabilities similar to the systems used for *SOF Precision Strike*, would be appropriate.[25] Collectively, a potential problem may arise in providing appropriate power supplies to these microsystems without "frying" the chips. For possible solutions to this and other power problems, please refer to the "sustain" section that follows.

The third requirement highlights the uniqueness of a third-wave SORE force which must "operate and blend into" first- and second-wave worlds. It portends that, even if available, standard third-wave C^4I systems may be inappropriate for SORE operations. For example, even though high-tech, third-wave communications systems will exist for team-to-team communications, like the Tactical Information Display

Source: P. J. Griffiths Magnum, "Wireless Networks," *Scientific American*, September 1995, 53.

Figure 4-3. Camouflage Is Critical

Helmet,[26] it does not "look and feel" like the sponsoring nation's equipment, nor does it "blend" into their low-tech environment. Rather than blend into the local environment, the helmet would merely flaunt SORE force presence and jeopardize their low profile assistance. Therefore, we may not want to employ it, since using it would defeat our purpose of training and developing the sponsored forces with their own equipment and in their own technological era.

To eliminate these problems, two solutions or approaches are suggested. First, we must be fully aware of and knowledgeable about the current technological state of our host. Next, we must be prepared to use the host's C^4I equipment or to deploy equipped with organic first- or second-wave equipment. We cannot expect their equipment to be as sophisticated as ours nor can we count on them to have sufficient C^4I assets to support us while in-country.[27] Therefore, in 2025, we must plan to arrive at the doorstep with their generation of equipment, which may be only slightly different from today's. This amplifies the need for SORE teams to be trained in a myriad of "old" and "new" technology, from 1980s-vintage to 2025 "third-wave" high-tech systems. This is particularly true for defensive SORE operations.

The second approach is to take advantage of third-wave technology to hide or camouflage "third-wave" capabilities in first- and second-wave C^4I equipment (retrofit) or to design high-tech systems in low-tech form or objects (mimic). The goal is to have third-wave C^4I technology available to the SORE team, yet conceal its presence from the local population and/or host. The concealment serves two purposes. First, it ensures our SORE teams have reliable, secure communications and up-to-date intelligence for their planning and protection. Secondly, it prevents SORE teams from intimidating or offending their hosts or tempting them with advanced technology before its time, since they must evolve at their own pace, not ours.

Without camouflage in these primitive environments, reliable, secure, interoperable C^4I may not be available to our SORE teams. The need for secure communications and updated intelligence even in a nonhostile environment is summarized in Joint Pub 3-07.1:

> A thorough intelligence analysis must focus on the political, social, scientific, technical, and economic aspects of the area as well as on an analysis of hostile elements. Active intelligence support must continue through to the end of the employment of military forces in support of a program. This continuous intelligence effort will gauge the reaction of the local populace and determine the effects of US efforts, as well as evaluate strengths, weaknesses, and disposition of opposition groups in the area.[28]

To arrive equipped with the third-wave C^4I tools desired, embedding the already mentioned "single chip C^4I system" alongside the rudimentary crystal inside a 1990s vintage Land Mobile Radio hand set (brick) may serve our purposes. The retrofitted "brick" would furnish the appropriate first-wave camouflage for our third-wave C^4I, allowing us to meld into the environment with a means to communicate on their local technological level, yet allowing third-wave interface for the SORE team.

Designing C^4I systems resembling or "mimicking" 1990s' era equipment—such as an aircraft mechanic's toolbox, a cigarette lighter, a wristband, or a canteen—exemplifies the notion. Another candidate would be a satellite communication antenna that looks like an ordinary "leaf." Similarly, miniature listening devices in the shape of lifelike insects, such as the "Fly on the Wall"[29] or "Robobugs"[30] concepts, could easily and transparently be distributed by the SORE teams to accommodate the collection task.

The fourth and final requirement—a critical component of SO today and just as valuable in 2025—is face-to-face communications. Keeping the "human in the loop" will be important for two main reasons.

> First, . . . SOF in direct combat with the enemy or in offensive operations have as their focus preparing foreign forces, either military or

paramilitary, to conduct operations on a wide range of tasks from combat to nation building, in peace, as well as war. Successful conduct of these operations relies on the ability of SOF teams to establish rapport with and positively influence those they train.[31] Secondly, in addition to standard conventional force products, SOF analytical requirements may include internal security force order of battle information, reaction time and size of opposing forces, weapon systems available to the security force, daily routine and habits of the security force and local population, security force communications, and detailed physical characteristics (such as construction materials) of specific buildings in the target area,[32] precision intelligence on urbanization trends and movements, or verification of questionable data.

As stated by Dr Larry Cable in a 1996 lecture to students of the Air War College, information of this nature, although it may be verified and enhanced by technological means, is most likely to come from HUMINT sources. He further stipulated that SOF's ability to make contact with and to gain the local security forces' confidence may provide one of the best tools of intelligence gathering and unconventional warfare.[33]

As such, these operations place a high premium on not only knowing the language of the people being taught but in having a thorough understanding of the culture and the area where these operations take place.[34] Even with extensive preparation, cultural differences and language barriers remain a major obstacle. Hence, taking advantage of training in "virtual" environments as well as employing an unobtrusive, possibly a "hearing aid" style, translator should overcome these barriers. Either way, it is important to note that, although technology might speed up the cultural indoctrination process and minimize the language barrier, unless the translator is transparent to the receiver it may only intimidate a lesser developed nation or tribe and/or offend nations of lesser development. With this in mind, exploiting the proposals for portable or handheld translators identified in the ***2025*** concept database should minimize their size and awkwardness.

More importantly, and as noted in Joint Pub 3-05.3, "because SORE forces focus on developing indigenous leaders, organi-

Source: Richard Pasley, "Wireless Networks," *Scientific American*, September 1995, 52.

Figure 4-4. "Blending in with the Locals"

zations, and individual skills, they conduct operations primarily on a personal level, rather than through transfer of hardware."[35] Thus, the focus of technology should be on improving the human's ability to learn new information faster, retain it longer, and assimilate ideas more rapidly in order to prepare them in less time for operations in countries with differing cultures, languages, dialects, and regional orientation interests.[36]

As a final note, the real focus of third-wave technology should be directed at enhancing the effectiveness of assimilating the individual versus "arming" them with "techno-gadgets." Collectively, the emphasis should be on the processes and systems that accelerate or advance language and cultural assimilation skills and improve the person-to-person contact so vital to SORE mission success.

Counter

Since World War I, airmen have had to control the air environment effectively to employ airpower. What is more, air and space superiority are virtually sine qua non for employing ground and naval forces. Information is the next realm we must control to operate effectively and with the greatest economy of force.

—*Cornerstone of Information Warfare*
Department of the Air Force

The application of C^4I countermeasures is another important enabling task of SORE. In fact, it is an integral component of any war-fighting concept that combines denial and influence of information, deception, disruption, and destruction to counter adversary C^2 while simultaneously protecting friendly C^2.[37] The five principal military actions used to achieve these results are operations security, psychological operations (PSYOP), military deception, electronic warfare (EW), and destruction. Up front, we recognize that most of SORE C^4I countermeasure systems will come from non-SOF resources since conventional and SOF will face similar "electronic" threats.

Some protection can be gained by enforcing good operations, computer, and communications security (OPSEC, COMPUSEC, and COMSEC) procedures. Poor OPSEC is not a new problem, but one that permeates SO operations today.

> A major problem in all SOF activities is denial of critical information about friendly intentions, capabilities, and activities to hostile elements. This is due to the fact that groups engaged in lawlessness and insurgency operations may be corrupted members of penetrated foreign governments. US and foreign personnel involved in SOF programs should be provided extensive OPSEC training to ensure effectiveness of their operations.[38]

Table 3

Counter Attributes

ATTRIBUTE	COUNTER
Interoperability	*Critical
Fusion	Critical
Portability	Desired
Transparency	Desired
Range	Desired
Capacity	Critical

**Critical* and *desired* refer to "level of need" for task accomplishment.

Coding/decoding methods, encryption/decryption devices, as well as a host of new security technologies could aid in solving the problem. As Dr Martin Libicki points out, "Although the contest between bit senders and bit blockers gets more sophisticated on each side, new technologies (multistatic radar, digital signal processing, spread-spectrum, public-key encryption and authentication) favor the bits getting through, uninterrupted, as well as without spoofing."[39]

PSYOP as "an aspect of information warfare as old as history"[40] will continue to be an invaluable countermeasure. The targets may not change, but the means to counter or affect them will. Communications support for PSYOP should concentrate on cultural assimilation, simple, and effective ways to deliver the information to the locals, and methods to negatively or positively persuade those individuals.

> Psychological operations . . . multiply [the] effect of military capability by communicating directly to their enemies the power of the US or coalition forces, threat of force or retaliation, conditions of surrender, safe passage for defectors, incitations to sabotage, support to resistance groups and other messages[41] as well as strengthening economic and diplomatic sanctions, and emphasizing the adversaries' isolation or weaknesses.[42]

Direct PSYOP support for SORE operations should be concentrated before arrival, to facilitate positive communication with the local population. This preparation may use different media (radio, leaflets, TV, holographics, etc.) to persuade or influence. In 2025, more advanced broadcasting and projection systems, which can operate from workstations in CONUS, and leaflets distributed with precision guidance systems to target audiences should be considered. Along the same lines, a Holographic Projector[43] could be used as a deception or PSYOP tool projecting images in the sky above the target audience. Translators could make television, radio, holographic broadcasts, or direct contact with enemy troops or citizens more effective. In fact, direct broadcast television (DBTV), which has more than a 100-channel capability and sells for less than $1,000 today, should be capable of providing "information on demand" in the future.[44] DBTV could be an inexpensive way to affect first- and second-wave nations in 2025.

Source: USSOCOM Pub 1, *Special Operations in Peace and War,* 2–17.

Figure 4-5. PSYOP in Action

DBTV would not only be useful as a preparation tool, it could pay high dividends as an "offensive" PSYOP tool. Just as TV mesmerized the US in the 1960s and China in the 1990s, it could be equally distracting or alluring to preindustrial and industrial nations in 2025. Broadcasting "free TV" 24 hours a day to specific targets groups could render them "immobile, infuriate the masses, or launch them into new directions." For example, broadcasting MTV, "Soaps," Talk Shows, and/or Educational TV for teens, and "fictional CNN" for the general public, business, military, and government could pay high dividends with minimal investment. The key is knowing the desired goal and the target audience, and then broadcasting the appropriate propaganda to achieve it.

Finally, "PSYOP is not only a user, it is a producer of intelligence, capable of contributing to the overall national effort as well as servicing its own needs."[45] To further explain, the extensive regional collection and assessment conducted for PSYOP may produce intelligence useful for other special or conventional operations. For example, the assessment data could be incorporated in the Virtual Reality Training Center for up-to-date regional awareness training.

In a collateral role, offensive and defensive SORE forces might be tasked to assist and support other information warfare (IW) activities—particularly in the "controlling information" role where SORE forces exploit the enemy's systems while protecting their own.[46] Since IW masks preliminary preparations and movements, overloading the enemy's command decision making allows us to precisely apply our combat power at his most vulnerable points.[47] Therefore, the SORE forces' role might be as simple as verifying the "Information Warrior's" information target. In-country acceptance of SORE forces makes them prime candidates for verifying "unconfirmed" data, providing realistic knowledge of exploitable targets for psychological operations or information warfare targets,[48] or for attaching monitoring devices (i.e., "tagging") on potential targets in the region.

Similarly, offensive SORE forces may be tasked to influence enemy perceptions using strategic perception management (SPM)[49] or one of the many other counterinformation systems directed at military deception, electronic warfare, and destruction. Many of these systems will be available through non-SOF or specialized SOF systems. Therefore, rather than address transatmospheric reconnaissance aircraft (TRA),[50] information systems weapons or electronic countermeasures,[51] defensive information warfare,[52] or high powered microwave and high power laser directed energy weapons (HPM)[53] in this paper, precise information can be found in the white papers dedicated to information dominance, such as *Information Operations, Counter Information,* and *S & R Information Operations.*

Finally, defensive SORE forces may be required to restrict the use of third-wave systems with a host entity unless the technology is camouflaged. The rationale is twofold. First, the open use of advanced technologies, such as handheld translators may be offensive to the receivers and subsequently impede interpersonal interaction. Second, since the ultimate goal of defensive SORE is to advise, train, and assist host-entities in the use of their own aerospace equipment, it is counterproductive to make them dependent on an advanced system and then remove it when SORE forces leave. Furthermore, teaching them how to effectively use their own air assets allows them to bring their own airpower to bear on the source of internal instability without simply "handing" them our advanced technology.

Sustain

I don't know what this "logistics" is . . . but I want some of it.[54]

As we make the mad rush into the next century, we cannot forget the basics of force survival. Although technology will play a pivotal role in many areas, the heart of all those advances will remain the individual.

This is especially true for SORE forces. They may deploy to built-up, fully equipped host entities who possess and maintain "creature comforts" and infrastructures conducive to successful operations and training. A more likely scenario, however, would be to employ SORE forces in preindustrial environments where conditions are more stark and less habitable. In these situations, their survival depends on "carrying-in" organic support. In this scenario, they must be self-reliant, innovative, and adaptable. This will be especially true for offensive SORE forces that may be isolated from more direct means of sustainment or support.

Assuming the latter is the norm, four main SORE sustenance needs must be considered: food, water, portable energy sources, and ammunition. Each is critical to the "survival" of the individual SORE warrior. Looking at the construct of Col John Warden's five-ring analysis of "The Enemy as a System,"[55] each SORE force member is, in fact, a system with its own ring of "organic essentials." Following his premise, SORE forces' survival can be affected if enemy actions are directed against this ring, or if inadequate attention is paid to ensuring that the needs of this ring are met. Accordingly, given our thesis that the "man-in-the-loop" is the prime actor and "effector" of change in 2025's less developed regions, improvements to these essentials must be foremost in our advances.

Following Warden's analogy, all systems require certain organic essentials to survive. Without an energy source (food, oxygen, and water), the human system will cease to operate. At the center of the human system is the decision-making mechanism—the brain. Organic essentials allow the brain to process inductive and deductive logic—without which, one cannot effectively function as a *brilliant warrior*, to use General Kelley's term. Obviously, without these basic essentials, a human body cannot survive. This observation may appear simplistic and it is. However, the essence remains—we must pursue methods and technologies that provide SORE forces the day-to-day capability to exist in any environment and for indefinite periods of time. Table 4 provides the task attributes and level of need to meet these requirements.

To begin, an individual must be put through a battery of tests to determine individual organic levels and nutritional needs. Then a survival package which is lightweight and compact can be devised and tailored for each force member. To accomplish this, we must pursue advances in food development such as biochemical-enhanced "hyper speed growth" seeds cultivated on portable substrates. Unfortunately, the "Chia Pet" is probably the only universally advertised "speed growth" method conceptually known to the general public today. Something similar to the Chia Pet concept, that is simple, fast, unobtrusive, and man-portable is needed to replenish SORE forces' nutrients "while on the go." The approach should seek to exploit chemically enhanced seeds, nuts, or grains which grow and produce "food" within a 24- to 72-hour period or less.

Table 4

Sustain Attributes

ATTRIBUTE	SUSTAIN
Portable	*Critical
Customized	Desired
Unobtrusive	Critical
Automatic	Ideal
Precision delivery	Critical

**Critical, desired,* or *ideal* reference "level of need" for task accomplishment.

These pursuits could be complimented by refined metabolic rate screening results obtained during individual assessment. The results of this screening, combined with nutritional-matching discussed above, will ensure enhanced performance during employment. A potential candidate is the human optimization of metabolic and behavioral response (HOMBRE) concept. With this system, we may be able to determine each SORE force member's metabolic type, then selectively enhance cognitive and physical performance through specific nutritional regimens.[56] Enhanced and peak performance on short-term tasks will help ensure success in any given environment.

Source: Miguel L. Fairbanks, "Technology for Sustainable Agriculture," *Scientific American,* September 1995, 149.

Figure 4-6. "Fast Food" Production for Deployed SORE Forces

Water purification agents and collection devices must be improved and made portable for forces in the field. A quick solution may be to use absorbent receptacles to collect dew, obtaining small quantities of water for force sustainment in a dry environment. Long-term, more exotic sources may be the manufacture of dry chemicals which, when combined, bond at the molecular level to produce water. An even more far-reaching approach may be to filter and purify body fluids to act as an interim water supply should extreme conditions arise. Presumably, humans can exist for weeks without adequate food since the body will compensate and feed off internal reserves. However, water must be available within days, or death will result.

Given the multitude of electronic and kinetic gear used by SORE forces, portable power sources will be crucial. Several technologies must be pursued to provide these sources. For example, since water is critical to existence, methods to extract power from the hydrogen compounds in these water sources could be adapted to SORE force needs, thus doubling the benefits of having the water! Similarly, battery packs must be more compact, lighter, rechargeable, and retain longer life on a single charge.

Assuming the philosophy that man is a machine, the potential exists to create and implement technologies to exploit human movement and central or autonomic nervous system activity as low-grade energy sources to provide that potential power supply.[57] Discounting initial insertion and aviation-related missions, SORE force members will take the tried-and-true method of transport—they will walk. We must harness and exploit that energy dispensing action. For example, the physical motion of walking may lead to development of "boot chargers" located in the heels of a force member's boots. The charger would operate or recharge as the member performs his/her daily routines. In the same vein, a plethora of other technologies

are projected which may provide alternative portable energy sources. They may range from lightweight, solar panel collection systems for daylight operations, to ambient lunar light collection panels for day-night capability, to miniaturized power-generating factories on a single microchip.[58] The technological leaps made in researching and powering solar-powered automobiles and satellites, as well as microscopic machines, should be investigated for SORE force application.

Finally, SORE force application may involve covert, clandestine, or hostile action. Accordingly, provisions must be made to arm and resupply the SORE warrior with first-to-third wave ammunition. While nonlethal application of force may be preferred, the nature of the SORE mission dictates possession of lethal weapons. When all else fails, a "gun," whether loaded with kinetic energy, high-powered microwave, or 1990s depleted uranium projectiles must be available to SORE forces. Expedient replenishment and replacement of first-, second- and third-wave ammunition sources must be considered. Potential solutions are precision-guided delivery systems and energy weapon recharging via direct satellite link. In both cases, sensors will monitor inventory levels and track source supply points automatically and replenish as needed. The latter concept is a "passive-push" replenishment system similar to today's Just-in-Time or Trickle Charge systems. This approach minimizes administrative communications that may compromise covert or clandestine units and optimizes use of limited replenishment assets. Without the "tools of the trade," SORE forces will be ineffective and at risk.

With sustainment, the enabling task discussion is complete. Having addressed those tasks and their relative importance, the next section of the paper summarizes our findings and includes some broad recommendations. For a detailed prognosis and evaluation of the systems and their underlying technologies, please refer to appendices A and B.

Notes

1. USCINCSOC Congressional Testimony, March 1995.

2. SORE force members will be recruited, assessed, retained, and employed based on actual performance. If a member's performance falls below acceptable levels, he/she will be returned to conventional forces or separated.

3. As noted in W. French Anderson's article "Gene Therapy," *Scientific American*, September 1995, 96–98B, significant progress in the realm of gene modification to affect gene-based disease has been made. Assuming quantum progress continues well into the next century, selective gene screening and DNA typing may well be applied to potential candidates. Anderson does not advocate an era of "eugenics" to alter composite gene pools. Similarly, the authors of this paper do not advocate the "super human" genetic application nor experimentation. However, the intent of this approach is to use DNA and genetic makeup as a tool for selecting the pool of SORE candidates who theoretically will be capable of replicating successful SORE operations based on those SORE forces whose genetic makeup is similar.

4. ***2025*** Concept, no. 900501, "Artificially Intelligent Word Processor," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

5. ***2025*** Concept, no. 900562, "A Selective Knowledge Pill," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

6. USCINCSOC Congressional Testimony, March 1995.

7. Lt Gen Jay W. Kelley, USAF, "Brilliant Warriors," *Joint Force Quarterly*, Spring 1996, 110.

8. James P. Marshall, "Near Real-Time Intelligence of the Tactical Battlefield," *Theater Air Campaign Studies Course Book* (Maxwell AFB, Ala.: Air Command and Staff College, 1996), 235.

9. USAF Scientific Advisory Board, *New World Vistas: Air and Space Power for the 21st Century*, summary volume (Washington, D.C.: USAF Scientific Advisory Board, 15 December 1995), 11.

10. USAF Scientific Advisory Board, "New World Vistas: Air and Space Power for the 21st Century" (unpublished draft, the information applications volume, 15 December 1995), 5.

11. Joint Pub 3-07.1, *Joint Tactics, Techniques, and Procedures for Foreign Internal Defense*, 20 December 1993, I-13.

12. Dr James Kvach, Armed Forces Medical Intelligence Center, ***2025*** Lecture, 31 January 1996.

13. Joint Staff Memorandum to the SECDEF, 19 December 1995, Subject: *Volume 4 (Future Capabilities)*, *Joint Planning Document for FY 1998 through FY 2003* (JPD FY98-03), Enclosure, 3.

14. *SPACECAST 2020, Air University into the Future, Operational Analysis*, Air University, 22 June 1994, 34.
15. Ibid., 35.
16. *New World Vistas*, summary volume, 10.
17. Ibid., 62.
18. *United States Special Operations Forces Posture Statement*, 1994, 4.
19. Joint Pub 3-05.3, *Joint Special Operations Operational Procedures*, 25 August 1993, VI-2.
20. *New World Vistas*, summary volume, 62.
21. Voice recognition and voice generation, gesture recognition and response, multilingual translation and generation, and brain control of computers technologies will all contribute to making sure the human is not the limiting factor.
22. ***2025*** Concept, no. 900263, "The All Seeing Warrior," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).
23. ***2025*** Concept, no. 900317, "Tactical Information Display Helmet," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).
24. John L. Petersen, *Road to 2015, Profiles of the Future* (Corte Madera, Calif.: Waite Group Press, 1994), 190–93.
25. Power and energy supply obstacles must be overcome when developing and employing these "micro" systems. Those organic needs are addressed in the Sustain section of this chapter.
26. ***2025*** Concept, no. 900317, "Tactical Information Display Helmet," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).
27. Nor does it allow us the opportunity to exploit our own technology in their environment—this will be explained in approach two.
28. Joint Pub 3-07.1, IV-1.
29. ***2025*** Concept, no. 900280, "Fly on the Wall," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).
30. ***2025*** Concept, no. 900341, "Robobugs," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).
31. Joint Pub 3-05.3, VI-2.
32. Ibid.
33. Dr Larry Cable, University of North Carolina, Wilmington, AWC Lecture, 31 January 1996, permission granted.
34. USCINCSOC Congressional Testimony, 27 March 1995.
35. Joint Pub 3-05.3, II-5.
36. ***2025*** Concept, no. 900624, "Hand-held Translator," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).
37. *JFACC Primer*, 2d ed., February 1994, 24.
38. Joint Pub 3-07.1, IV-6.
39. Dr Martin Libicki, "What Is Information Warfare?" *Strategic Structures Course Book*, vol. 2 (Maxwell AFB, Ala.: Air Command and Staff College, 1996), 684.
40. Ibid., 685.
41. Frank L. Goldstein, *Psychological Operations—Principles and Case Studies* (Maxwell AFB, Ala.: Air University Press, 1996), chapter 1.
42. Jeffrey B. Jones and Michael P. Mathews, "PSYOP and the Warfighting CINC," *Joint Force Quarterly*, Summer 1995, 29.
43. *SPACECAST 2020, Air University into the Future*, 36.
44. Gen Wayne A. Downing, USA, "Joint Special Operations in Peace and War," *Joint Force Quarterly*, Summer 1995, 25.
45. Goldstein, 147.
46. *Cornerstones of Information Warfare*, Department of the Air Force, 11.
47. *Warfighting Vision 2010, A Framework for Change*, 1 August 1995, Joint Warfighting Center, Doctrine Division, Fort Monroe, Va., 12.
48. Dr Cable, AWC Lecture, 31 January 1996, permission granted.
49. Jeffrey Cooper, *Another View of Information Warfare, Conflict in the Information Age*, SAIC, 30.
50. ***2025*** Concept, no. 900351, "Transatmospheric Reconnaissance Aircraft (TRA)," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).
51. *New World Vistas*, summary volume, 60.
52. Ibid., 10.
53. Ibid., 46.
54. Used in opening remarks delivered by The Honorable John H. Dalton, secretary of the Navy, while christening the USNS PATUXENT (T-AO-201), at Avondale, La., 23 July 1994. Specifically, Mr Dalton's context was: "Those are the words of Fleet Admiral Ernest King shortly after he became Commander-in-Chief of the US Fleet and Chief of Naval Operations. The year was 1942. America had suffered a surprise attack and her leaders realized that a long, bloody war lay ahead . . . a war that would consume vast quantities of fuels, supplies and materials. It was a war in which all Americans, from admirals commanding fleets to the men and women working in the shipyards and factories on the 'home front,' would learn the word 'logistics' and its importance in achieving victory." Although the context may change, the concept as applied to SORE needs remains timeless. In order to achieve victory, we must ensure the "logistics," vis-à-vis, sustain requirements, are provided to our fielded SORE forces.
55. Col John Warden, USAF, Retired, "The Enemy as a System," *Strategic Structures Course Book* (Maxwell AFB, Ala.: Air Command and Staff College, 1996), 437–39.
56. R. Wiley, HOMBRE Concept Submission, *Technology Initiatives Game 95*, Item 111-1.
57. ***2025*** Concept, no. 900123, "Body Heat As a Low Grade Energy Source," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).
58. Kaigham J. Gabriel, "Engineering Microscopic Machines," *Scientific American*, September 1995, 118–21.

Chapter 5

Conclusions and Recommendations

Like Greely, I too would urge young men to go west—would urge airmen to look to the frontiers of air and space power. New doctrine is desperately needed there. The doctrinal gaps . . . are probably as great as those faced by the ACTS [Air Corps Tactical School] pioneers 60 years ago as they contemplated the doctrinal gap between an air service and an air force. Stalking and conquering frontiers are clearly the Air Force heritage. That alone should tell us where the future lies.

—Carl H. Builder

Currently, the Air Force is struggling with its frontier missions and those missions' place in doctrine. Most are familiar with our frontiers in space and information. Air Force leadership, past and present, has placed significant emphasis on coming to grips with the Air Force role in these areas. Other frontiers have not been lavished with as much attention. The aviation piece of SORE may provide a breakthrough in this regard. Although not a "glamorous" mission, it is nonetheless a vital one if the Air Force is to come to understand its role in this frontier of warfare.

In 2025, the United States will face challenges to its leadership and interests from nations and entities in the first, second, and third waves. SORE forces will be the military forces organized, trained, and equipped to engage in the first and second waves to protect and further US interests. SORE is not just a ground or riverine mission suited to "green berets" and SEALs. There is a critical airpower component to SORE that the Air Force must prepare itself to meet. Many first- and second-wave nations and entities will face threats to their internal security that require the proper use of airpower. The fledgling air forces of these entities will require assistance in developing adequate tactics, procedures, maintenance, supply, and other support systems within their own technological limitations.

The challenge to all SORE forces is fourfold. First, they must possess the cross-cultural skills necessary to build the trust that underlies productive interpersonal relationships. Second, they must use these same cross-cultural skills to make themselves as "transparent" as possible in the environments in which they operate. This is particularly true for SORE offensive operations which are almost always covert or clandestine. Third, they must exploit the advanced technology at their disposal, to prepare and protect themselves in the context of first- and second-wave societies. Lastly, SORE forces must ultimately ensure clients do not develop any dependence on them, lest we set the stage for failure when we depart.

The myriad of challenges can be overcome and the capabilities achieved using both SOF and non-SOF resources. In fact, many systems forecast for SORE operations in 2025 may not be SOF-unique. However, to ensure the SORE tasks are accomplished, a combination of conventionally developed, commercially leased resources, or specially designed SOF-unique systems must be available to ensure SORE conceptual employment goals are met.

We recommend the following concepts and systems be pursued for SO Regional Engagement operations: (1) Designing a recruitment and selection system—Virtual Reality combined with genetic and cognitive

bination of conventionally developed, commercially leased resources, or specially designed SOF-unique systems must be available to ensure SORE conceptual employment goals are met.

We recommend the following concepts and systems be pursued for SO Regional Engagement operations: (1) Designing a recruitment and selection system—Virtual Reality combined with genetic and cognitive learning ability screening; (2) Developing a similar or exclusive Virtual Reality Training/Battlefield Awareness Center for training, rehearsal, and assessment; (3) Retrofitting first- and second-wave C^4I equipment with "third-wave" technology (the Land Mobile Radio "Brick" example); (4) Designing third-wave equipment, "mimic systems," camouflaged in first-and second-wave form (a C^4I system disguised as an aircraft mechanic's toolbox or a SATCOM antenna shaped like an ordinary leaf) or designing third-wave technology that "fits" first- and second-wave signature (the "Fly on the Wall" or "Robobugs" collection devices; or "The All Seeing Warrior" contact lens); (5) Procuring standoff PSYOP broadcasting and projection systems as well as precision-guided delivery systems; (6) Minimizing language barriers with "transparent" translators; (7) Taking advantage of standard third-wave C^4I systems such as the Global Surveillance, Reconnaissance, and Targeting System, Global Positioning System, Strategic Perception Management systems, distributed satellite systems, and direct satellite link to large aircraft and URAVs, to name a few, for interoperability and compatibility across all services; and finally; (8) Pursuing sustainment systems such as fast growing food, chemically bonding water capsules, microchip power supplies or "recharging combat boots," as well as some type of "passive push" replenishment systems and concurrent nutritional enhancement regimens—HOMBRE.

Our final recommendation is to capture the requirement for a SORE capability in defense planning guidance. Without such emphasis and resultant funding, the research and development of these systems' underlying technologies will not be possible. Without these "parts-pieces," the systems needed will not be fielded, and our "2025 SORE Warriors" will be out of place in "King Arthur's Court." As Carl Builder notes,

> It takes farsightedness and guts to build an armed force that will only be called to fight in, say, a decade. One has to guess, as best one can, what resources will be available, what kind of opponent the force will be called on to face, and what kind of environment they will have to operate in. Those fundamental questions settled, the time comes to decide how to best meet the challenges ahead.[1]

The time is now to make these decisions. The current draft of Air Force Doctrine Document (AFDD) 1 is not a pioneer effort regarding airpower in Special Operations. It is the hope of the authors that this white paper will contribute to the "pioneer" spirit that Carl Builder calls for in the development of future airpower doctrine.

Note

1. Martin van Creveld, *The Transformation of War* (New York: Free Press, 1991), 117.

Appendix A

Systems and Underlying Technologies

We cannot always be on the leading edge of technology ourselves. It is too expensive. We have adopted a program of prudent innovation, choosing carefully which technological paths to take and fully leveraging the research conducted by the Services, other government agencies, and the private sector.

—USCINCSOC Congressional Testimony
27 March 1995

Special Operations will require training, C^4I, countermeasure, sustainment and movement (transportation) systems, and/or concepts that can support a wide variety of missions, ranging from nation assistance or civil-military activities in friendly environments, to assistance of conventional forces in hostile environments, to special operations in enemy-held, enemy-controlled, or politically sensitive environments. These systems must provide the SORE warrior the tools necessary to carry out missions of controlling, exploiting, and enhancing overall force effectiveness.

This appendix is divided into seven sections—train, observe, communicate, decide, counter, sustain, and move. Each section identifies those systems that are SORE unique or reliant on other sources, ranging from conventional forces, commercially leased, host "entity," to SOF-unique systems developed for another "arm" of SOF. "Dependencies" matrices are provided for each function, where a quick picture of those systems can be referenced—table 6 discusses training; tables 8 to 10 show C^4I; table 12 reflects countermeasures; table 13 details sustainment, and movement systems are spelled out in table 14. Within each major section, the enabling task's attributes and measures of merit (MOM) are laid out in table 5 for training, 7 for C^4I, and 11 for countermeasures. The system descriptions follow in the text.

Recruit, Assess, and Train Systems

SORE recruitment, training, and assessment regimens and the system attributes are presented in table 5. The table presents the attributes required of a training system with the respective measures of merit needed to gauge the effectiveness of that system. The effectiveness is based on the outcome and qualities of the individual skills learned. The system (as defined) must act as a filter and trainer for potential SORE candidates. For example, in the selection and training process, a person's ability to adapt to a culture, learn a language, operate a vintage aircraft, or act as an individual negotiator in his/her region of employment must be the outcome and will be the measure. Hence, the matrix shows those requirements and effectively rates them on a scale of critical to ideal, as discussed in chapter 4. In addition, the force qualities' level of need is targeted against its application to each task—recruit, assess, or train. As a note of caution, the systems may fill the requirements of all tasks, however the scale of importance will vary greatly depending on the status of the process (i.e., stage of recruitment, level of assessment after selection, or mission training requirements based on specific

Table 5

Recruit, Assess, and Train System Tasks, Qualities, and Measures

TASK	CRIT/DES/IDL			FORCE QUALITY	MEASURE OF MERIT
R, A, T	X			Cult/Pol Sensitivity	Multiwave Skilled
R, A, T	T	A	R	Regional Orientation	Number of Regions Support
R, A, T	X			Language Prof	Number of Languages Prof
R, A, T		X		Negotiation Skills	Number of "Successful" Results
R, A, T	R		A/T	Psychological Profile	Based on Empirical Data
R, A, T		R	A/T	Cognitive Learn Ability	Retention Testing/Evaluation
R			X	Physical Attributes	"Look the Part"
A, T	X			Adaptability	Number of Variations Possible
A, T	T	A		Interactive/Realistic	Number of Scenarios/Waves
A, T			X	Individually Tailored	Number Trained/What Level
A, T			X	Portable	Time/Transport Require to Move
A, T	T	A		Interoperable	Near-Real-Time Input and Update

R=Recruit, A=Assess, T=Train, Crit=Critical, Des=Desired, Idl= Ideal, X=Common

tasking). On a linear scale, as the system outcome draws closer to actual employment, level of criticality increases. Within the table, common criticality levels reflect an **X.** Where levels of importance vary, the task affected falls under the relevant criticality column.

Several training systems and concepts exist or are projected which may be unique to SORE recruitment, assessment, and training or may be drawn from other sources. As depicted in table 6, these systems could be beneficial but are not essential to SORE training.

The Virtual Reality Training Center/Virtual Battlefield allows participants, despite their geographic location, to simultaneously visit the same virtual battlefield in whatever type of tank, plane, ship, or system they will be tasked to use. They "see" the battlefield from their own individual perspective which enables simultaneous viewing of the battlespace or the peacespace by all participants. Similarly, this approach will allow for real-time simulations—giving the force

Table 6

Training Systems' Dependency Matrix

RECRUIT, ASSESS, TRAIN SYSTEMS	SORE Source	NON-SOF Source	OTHER SOF Source	HOST Source
Virtual Reality Trainer	X		X	
HOMBRE	X			
Rehearsal System		X	X	
"Gumping" A/V Lib		X		
Selective Knowledge Pill			X	
AI Word Processor		X		

commander real-time, hands-on experience in the battle or peace space, and will afford the opportunity to try modified and divergent tactics and will interpret results, while the mission is in virtual progress. This virtual battlefield approach offers the specialization and evaluation required without the potential for deadly mistakes prior to employment. Similarly, this approach also tracks real-time actions taken as they are played out for subsequent mission preparation and use by other teams.[1]

To create a realistic "virtual" environment will require technology from multiple sources. Data fusion and image-processing techniques will be needed to acquire, transfer, analyze, display, and interpret raw intelligence to change it into useful, usable information in real time.[2] Virtual reality and holography technology must be available. As these technologies proceed, not only will they be used for the Virtual Battlefield System at home, but they will allow fielded SORE forces to take advantage of full-color, three-dimensional projection transmitted to their employment location on demand.

Similarly, high-performance computing[3] with extremely high-performance digital vector and massive parallel processor architecture will be needed to process the plethora of data in real time. Without this high-speed capability, information saturation will inevitably occur. Molecular nanotechnology follows the same principle of building "things from the bottom up." Working at the individual atomic level, it must be possible to exploit this bottom-up approach to training the regional warrior, from accession through separation, using molecular sized machines to put information together in predetermined configurations.[4] If we assume nanotechnology will effectively size information to the molecular level, we can then use the principle of condensed charge technology to produce small, tightly bound dense clusters of electron charges of enormous power relative to their size and effectively integrate the spark, or more accurately micro-arc discharges, into our system to take advantage of the phenomenon.[5] Assuming human-system interface can be achieved, information can then be made, controlled, and used on command by the SORE member on the ground.[6] As situations and environments change, regional engagement operators must not be surprised by the unexpected. Recurring training, by "plugging in," to the "home-based" system will be the most effective method to keep surprise to a minimum.

Further, to optimize the cognitive learning skills of the individual, the Human Optimization of Metabolic and Behavioral Response (HOMBRE) system attempts to match the nutritional regimen of SORE intermediary metabolic profiles to systematically and sequentially enhance the needed cognitive performance.[7] The system will match the regimen to the individual and occupy a "feed and forget" phenomenon to promote and predict successful performance.[8] While the input and feeding may be needed for short durations, the possibility exists that this approach can be applied over longer periods as the situation dictates. Further, reverse engineering may allow for the same process to be applied in selecting SORE candidates, after sufficient data is obtained, which will point toward the most effective metabolic rates to screen and recruit for new accessions.

Determination of metabolic genotypes will be one of the underlying technologies needed for this enhancement process to be possible. The notion of gene typing and selective enhancement is feasible. The requirement and capability for enhanced signal and pattern discrimination capability currently exist.[9] The system matches the prognosis regimen to the individual instead of mass application and thus

increases probability of predicted outcome. Using this approach, metabolic rates can be limited and thus be more effective. The process can work in concert with other systematic enhancements or serve in a stand-alone capacity.

Dependencies or Training Systems Provided by Non-SORE Sources

Advancing development by related forces or scientific fields should make these systems available from other employment efforts. Accordingly, SORE application and system modification should occur as these technologies evolve. For example, if available through other sources, the "Rehearsal for all Missions System,"[10] could provide an additional resource for realistic training, while the "Gumping Audio and Video Library"[11] could provide the highly motivated individual another tool to train at their own pace and convenience. The "Artificially Intelligent Word Processor"[12] might be used for day-to-day training and preparation of conventional forces or corporate employees, or for tracking individual work progress automatically without the associated cumbersome filing and status system of today. The final conceptual approach to developing a "selective knowledge pill" relates directly to enhancing brain functions by intentionally introducing chemical imbalances in the central nervous system stem core. Detailed research must be conducted before this aggressive application can occur; however, the same principle as applied to behavior modification can be used. Obviously, SORE force training would benefit from these advancements, yet development should not occur based solely on RE mission requirements.

C^4I Systems

Table 7 displays the attributes needed in SORE observe-communicate-decide systems. The matrix shows the relationship between the task, its "level of need," the force quality or attribute needed to support the task, and the measure to

Table 7

C^4I Tasks, Force Qualities, and Measure of Merit Matrix

TASK	CRIT/DES/IDL			FORCE QUALITY	MEASURE OF MERIT
O, C, D	X			Face-to-Face Contact	100% w/locals / min with C^2 at HQ
O, C, D	X			Transparent	Blends into 1st/2d wave worlds
O, C, D	X			Interoperability	With standard C^4I systems
O, C	X			Divergent and/or Fused	Intel, surv, comm, weather, etc.
O, C, D	X			Secure	95%
O, C, D	O/C	D		Portable	Under 1 lb.-unobtrusive
O, C, D		X		Range	Global and Local
O, C, D	C	O/D		Capacity	Giga/terabits/sec
O, C, D	C	O/D		Speed	Near Real Time
O	X			Resolution	High
O, C		X		Survivability	All Wave
O, C, D		X		Accuracy	95%

O=Observe, C=Communicate, D=Decide, Crit=Critical, Des=Desired, Idl=Ideal

determine the system's merit. Again, within the table, a single "X" in either the critical, desired, or ideal column indicates the same "level of need" crosses all three tasks. When the level of need differs among the three tasks, the individual task's "level" is indicated by its "initial" in the appropriate—critical, desired, or ideal—column.

In all the *unique* SORE systems listed in tables 8 through 10, "transparency" or "packaging" is the principle priority. If forces cannot "blend" into their first- and second-wave environments, success in their operational employment will be suspect.

Observation or Collection Systems

Table 8 lists the collection systems sourced by SORE and those expected to be available through other sources. All would be useful to the SORE warrior; however, only the first- and second-wave "retrofitted or mimicked" systems should be organically sourced by SORE. All the other systems should be available through other awareness as indicated in the table.

A host of retrofitted and "mimic" observation systems resembling twentieth-century objects should be valuable in first- and second-wave environments. For example, embedding (retrofitting) host entities' collection equipment with third-wave technology or designing listening and audio devices resembling ordinary 1990s' "stuff" such as an aircraft mechanics toolbox, canteen, or cigarette lighter should be pursued. The underlying technologies for these retrofitted or "mimicked" systems might be metal-oxide semiconductors, CPUs on a single microchip, high-performance computing, electromagnetic communications, and divergent detection and resolution technology. Critical dependencies include technologies that interface system actions to communication networks for interoperability, fusion, and long-haul transmission.

Table 8

Observe Systems' Dependency Matrix

"OBSERVE" SYSTEMS	SORE Source	NON-SOF Source	SOF PS Source	HOST-ENTITY Source
Retrofitted 1st/2d Wave	X			
"Mimicked" 1st/2d Wave	X			
All Seeing Warrior		X	X	
Fly on the Wall/Robobugs		X	X	

Dependencies or Observation Systems Provided by Non-SORE Sources

The remaining collection systems will be equally valuable to conventional forces and should be fielded by non-SOF resources. The "All Seeing Warrior," a contact lens–like display for a warrior which provides all sensor, surveillance, reconnaissance, intelligence, and aircraft data at the blink of an eye, creating a seamless, real-time display for unsurpassed situational awareness[13] is a potential candidate. The same underlying technologies needed to build other collection platforms apply, with the addition of nanotechnology to miniaturize the system, as

well as a safe, nonirritating material to make the lens comfortable. Critical dependencies include commercial adaptation, data compression and transmission technology, divergent detection and resolution technology, and fused, interoperable communication systems.

The "Fly on the Wall"[14] or "Robobugs"[15] concepts provide the foundation ideas where miniature, remotely controlled "robot bugs" embedded with audio and video sensors or lasers are used for data collection or destruction. Underlying technologies are Alife techniques, nanotechnology, metal-oxide semiconductors, and single-chip CPUs.

Communications Systems

All of the systems identified in table 9 are required for SORE forces to communicate among themselves and/or back to headquarters. Only the "real" first- and second-wave equipment or the "retrofitted and mimicked" systems should be sourced by SORE. All the other systems are equally valuable to conventional forces and the commercial sector, thus should be available through alternate sources.

Actual first- and second-wave communications equipment may be needed in 2025. Standard twentieth-century communications equipment like today's communications systems—land mobile radios (bricks), high frequency (HF) radios, tactical satellite systems (TACSAT), telecommunications devices such as digital switching systems, and computers must be available and kept operationally current. This equipment may be the only viable method for SORE forces to interface with host equipment.

The most important force qualities in the next two concepts are transparency, interoperability, and fused or divergent data. Without these third-wave qualities, we cannot guarantee that SORE forces operating in crude surroundings will have access to third-wave technology and/or systems.

The first concept is retrofitting or camouflaging "third-wave" micromechanical single chip systems into the host's low-tech apparatus. For example, a 1990-vintage land mobile radio equipped with a C[4]I microchip could provide the

Table 9

Communications Systems' Dependency Matrix

"COMMUNICATE" SYSTEMS	SORE Source	NON-SOF Source	SOF PS Source	HOST-ENTITY Source
First/Second Wave Equip	X			X
Retrofitted 1st/2d Wave Equip	X			
"Mimicked" 1st/2d Wave	X			
Translators		X	X	
Tactical Info Display Helmet		X	X	
VSAT		X	X	
Distributed Satellite Sys		X		
Fiber and Satellite Sys		X		
Direct link to URAV/Lg A/C		X		
Transatmospheric Recc Aircraft		X		

communication link needed for all ranges and levels—from first through third-wave environments.

The other method is designing custom communications systems that "mimic" or "fit" into a first- or second-wave environment. For example, a satellite communications antenna that looks like an ordinary "leaf" that can be easily set up by "planting" it in the ground would be invaluable in the jungle or an urban area. Or, as described in the "observe" section, equipment built to look like 1990s' everyday articles but are actually sophisticated, third-wave communications equipment, could be invaluable collection aids.

The primary underlying technologies for all of these systems will be metal-oxide semiconductors, CPUs on a single microchip, and high-performance computing. In addition, these systems will require interface to the communications networks described in the following section.

Dependencies or Communications Systems Provided by Non-SORE Sources

First, a wide array of language translators suggested in the ***2025*** concept database should be available and beneficial to the SORE warrior, especially in PSYOP where translation could enhance television and radio broadcasts or direct contact with enemy troops or citizens. However, unless transparent, they would have minimal use to the SORE warrior in the field. Therefore, a translator resembling a "hearing aid" would be the most beneficial. Other potential systems include the "Universal Language Translator,"[16] a pendant-size translator capable of translating voice both to and from a receiver, and several variations of the same concept, the "Handheld Translator," the "Portable Language Translator," and/or the "Universal Translator."[17]

A tactical information display helmet, a helmet that provides the warrior a full spectrum of C^4I displayed across a face screen and controlled via voice or gesture,[18] coupled with a very small aperture antenna (VSAT) capable of transmitting audio, video, and sophisticated computer-generated data around the globe,[19] would be a tremendous combat field device. However, the helmet may be perceived as threatening in a nonhostile environment, and thus unusable until engaged in a combative operation. Again, underlying technologies include, but are not limited to, metal-oxide semiconductors, CPUs on a single microchip, and high-performance computing with a strong dependency on interface to the communications networks described below.

The key to all the C^4I systems discussed thus far, and in the next two sections; whether for collection, communication, decision-making, or countering, is interoperability via fiber and/or satellite networks. As cited in the *New World Vistas* report,

> Distributed satellite systems, partly or wholly commercial, are a natural way to provide affordable connectivity where fiber is nonexistent. We depend more and more on commercial terrestrial communication networks because they are redundant, reliable, survivable and cost effective. We seem to insist, however, on developing military satellite communication (SATCOM) systems in spite of their exorbitant cost and limited performance.
>
> During the next decade commercial SATCOM systems will exceed the capacity, reliability, and survivability of the military system. Commercial systems will have multiple ground stations which connect to the world wide fiber system. They will eventually use laser cross-links and down-links that will dramatically increase redundancy of the systems. It is likely that the commercial systems can be used for military purposes more reliably than can dedicated systems. This will be especially true if other nations develop anti-satellite systems.[20]

An alternative is using direct satellite link to large aircraft and URAVs, which requires a much smaller architecture and is less expensive.[21] Authors of *New World Vistas* reinforce the notion. Specifically, they assert that: "Certainly direct satellite links should be provided to all air lifters, AWACS, Joints STARS, URAVs, and tankers. Commercial carriers will probably suffice for the air lifter links and perhaps for the tanker links."[22] They detail the communication ties in great depth. For example,

> We estimate that MHz bandwidth is possible [for direct communications between high performance aircraft and satellite] if the fighter aircraft has a conformal phased array antenna. Cost of this is very high. It is now true that fighter aircraft are seldom out of range of communication with large aircraft such as a tanker, AWACS, or Joints STARS.
>
> As high altitude URAVs, enter the theater in large numbers, line of sight communications between them and a fighter aircraft will be reliable. A URAV at 60,000 feet can transmit line of sight to a fighter at 20,000 feet over a range of over 400 NM. Line of sight is not necessarily the limit of communication range for a high power transmitter . . . reliable communications over long range to standard antennas onboard a fighter aircraft can be accomplished without direct satellite links.[23] The deployment of airborne transmitters and satellite receivers in a bistatic[24] geometry . . . may be the ultimate system to provide what AWACs and Joint STARS provide today.[25]

A similar alternative may be the application of the transatmospheric reconnaissance aircraft methodology of providing real-time surveillance when ASAT knocks out our satellites. It operates below ASAT level and above SAM level.[26]

Warfighting Vision 2010, A Framework for Change suggested commercial adaptation for improving future communication networks.

> C^4I for the Warrior concept integrates commercial and military networks and systems. This "Systems of Systems" maximizes feasibility, interoperability, capability, cost, security, availability, precedence and assures military service . . . Artificial Intelligence (AI) supports more efficient fusion and fully integrated multimedia, multi-functional processors capable of near real-time decision aiding. Multilevel Security (MLS) solutions include multiple layer encryption, combined with electron, benign, transparent cryptographic key distribution and automated key management approaches. Network security devices provide the flexibility to maintain security without degrading operational effectiveness. Data compression and transmission technologies involve increasing speed and efficiently while decreasing the cost of processing and transferring digital information, including voice, data, imagery and video. Computing before communicating is increasingly important as computer technology outpaces increased bandwidth technology.[27]

Collectively, these technologies will be the underlying building blocks necessary for successful integration of SORE communications requirements. The need for many of these technologies will be widespread, serving a diverse audience ranging from business, to government, to the military, and to the general public. Therefore, availability of these technologies and systems should be common place and not sourced by SOF alone.

Decision Systems

As table 10 indicates, none of these decision systems will be developed solely for SORE forces. However, all would be extremely beneficial for SORE operations, especially in their collateral mission of Information Warfare. The purpose of presenting these systems in this white paper is to ensure the conventional forces pursue development.

The most important force quality indicators or attributes required in these decision systems or "Systems of Systems" are interoperability and fusion of multiple sources of information. Range and "packaging" will also prove important

Table 10

Decision Systems' Dependency Matrix

"DECIDE" SYSTEMS	SORE Source	NON-SOF Source	SOF PS Source	HOST-ENTITY Source
GSRT-Global Surv/Recon/Trk		X		
GPS-Global Positioning Sys		X		
Holographic C^2 Sandbox		X		

for SORE operations. These requirements are noted by previous authors of both *SPACECAST 2020* and *New World Vistas*. Specifically,

> The Global Surveillance, Reconnaissance, and Targeting System (GSRT) provides omni-sensorial collection, processing, and dissemination in real time. Creates virtual reality images of the area of interest and could be used at all levels of command to provide situation awareness, technical and intelligence information, and two-way command and control.[28]
>
> Similarly, an ultra precise, jam resistant Global Positioning System (GPS),[29] which would be an advancement over today's GPS, could provide . . . increased accuracy on the order of centimeters, fusion with other sensor assets, enhanced on-board computational capabilities, and a high data rate transmitter using low power and spread spectrum technology. [The RE force member] would employ a system of coded signals to provide multi-level, fused information and selectable accuracy to deny capability to all but selected [or verifiable] users.[30] It should provide precise and absolute positioning and timing which has a 30 cm spatial accuracy and 1 nanosecond (Ns) timing accuracy.[31]

A Holographic C^2 Sandbox is another potential decision aid for a commander "back at headquarters" or to the SORE "grunt" in the field. It would provide a complete picture of the battlefield by injecting information on a real-time basis. This system, like the GSRT system described above, requires image processing, holographic neural technology, and wide baseline interferometric synthetic aperture radar imaging technology.

Counter Systems

Table 11 displays the critical attributes needed in counterinformation or countermeasure systems designed solely for SORE or available to SORE. The matrix shows the relationship between the task, its "level of need," the force quality or attribute needed to support the task, and its measure of merit.

Table 11

Counter Tasks, Force Qualities, and Measures of Merit Matrix

TASK	CRIT/DES/IDL			FORCE QUALITY	MEASURE OF MERIT
Counter		X		Transparency	Blends into 1st/2d wave worlds
Counter	X			Interoperability	With standard C^4I systems
Counter	X			Fusion	Intel, surv, comm, weather, etc.
Counter		X		Portability	Under 1 lb.-unobtrusive
Counter		X		Range	Global and Local
Counter	X			Capacity	Giga/terabits/sec

Crit=Critical, Des=Desired, Idl=Ideal

As table 11 shows, the most critical attributes to counter adversary information exploitation attempts are interoperability, fusion, and capacity. The only countermeasure systems unique to SORE, as depicted in table 12, directly support PSYOP missions—the advanced broadcasting system and the holographic projector. The other systems are generic to all forces' requirements and should be developed/sourced by collateral entities.

Interoperability, capacity, and range are imperative to transmit large quantities of data to the target. For example, an advanced broadcasting system, which may be nothing more than a simple loudspeaker system but allows delivery from a standoff point or is capable of distributing leaflets with precision to its target audience, will require a wide "bandwidth" for execution. The same is true for the Holographic Projector[32] which could communicate US objectives by projecting "holographic" images directly into the region of concern. A few of the underlying technologies associated with these systems are image processing, holographic neural technology, and wide baseline interferometric synthetic aperture radar imaging, as well as standard communications networks.

Table 12

Countermeasure Systems' Dependency Matrix

"COUNTERMEASURE" SYSTEMS	SORE Source	NON-SOF Source	SOF PS Source	HOST-ENTITY Source
Advanced Broadcasting	X		X	
Holographic Projector	X		X	
Direct Broadcast TV		X	X	X
SPM-Strategic Perception Mgt		X		
HPM		X	X	

Dependencies or Counter Systems Provided by Non-SORE Sources

Direct Broadcast Television, a 100 channel, relatively cheap system (less than $1,000) today, should be capable of "information on demand" in 2025. It will be an inexpensive way to broadcast PSYOP messages to desired audiences. It is being researched and fielded by the commercial enterprises; therefore, off-the-shelf purchase of these types of systems is suggested.

Many types of information system weapons and electronic countermeasures will be devised by the various services. Two possibilities are

> High Powered Microwave and High Power Laser Directed Energy Weapons. These speed of light weapons, with the full spectrum capability to deny, disrupt, degrade and or destroy, will continue to evolve and may eventually replace most traditional, kinetic energy explosive driven weapons and self protection countermeasure systems.
>
> However, there are five innovative technologies required for "energy frugal" directed energy weapons. Specifically, they are high, light weight optics, HPM antennas using thin membrane fabrication, high-power short-wavelength solid-state lasers, high average power phase conjugation, new approaches to adaptive optics and phased arrays of diode lasers.[33]

Whether used in combination or in singular application, these technologies and their ensuing systems may prove invaluable for SORE countermeasure efforts, especially in collaboration with information warfare practices. Finally, we must

remember the eloquence of the *New World Vistas* report in addressing the collaborative and defensive efforts. Specifically,

> defensive IW will be pursued by the commercial community because of the obvious effects that malicious mischief can have on commerce. The military problem is, however, likely to be different enough that some effort will be required. The commercial solutions should be monitored closely for possible application or technology breakthroughs.[34]

One approach for SORE application may be to build a Strategic Perception Management system. Under this concept, new tools provided by the "Information Revolution" are so formidable that when they are employed to affect enemy perceptions, they could provide a war-winning, or at least war-deterring capability.[35] This may be the ultimate countermeasure for the technologies developed to measure, enhance, compensate, or convince the friendly decision maker.

Sustain Systems

Sustenance of the individual will be crucial for SORE operations. A host of technological leaps and applications will suffice to meet these needs. The focus, however, must be to meet the organic essentials of the human system by providing the nutrition, water, power, and ammunition required. Table 13 provides the dependencies as they relate to development of the systems.

Before we can feed SORE force members, we must determine individual organic levels and nutritional needs. Then a lightweight and compact survival package can be devised and tailored for each force member. To accomplish this, we must pursue advances in food development such as biochemical-enhanced "hyper speed growth" seeds cultivated on portable substrates. Something similar to the "Chia Pet" concept, that is simple, fast, unobtrusive, and man-portable is needed to replenish SORE forces' nutrients "while on the go." The approach should seek to exploit chemically enhanced seeds, nuts, or grains which grow and produce "food" within a 24- to 72-hour period.

Table 13

Sustain Systems' Dependency Matrix

SUSTAIN SYSTEMS	SORE Source	NON-SOF Source	SOF PS Source	HOST-ENTITY Source
"Chia Pet"-Fast Food	X			
Portable Water Supplies	X	X		
Portable Power Generators		X		
Passive Push Replenishment		X		

Refined metabolic-rate screening, combined with nutritional matching, will ensure enhanced performance during employment. A potential candidate is the HOMBRE concept. With this system, we may determine each SORE force member's metabolic type, then selectively enhance their cognitive and physical performance through specific nutritional regimens.[36]

A quick solution for water purification or collection may be to use absorbent receptacles to collect dew, obtaining small quantities of water for force sustainment in a dry environment. A long-term, more exotic source may be the manufacture of dry chemicals which, when combined, bond at the molecular

level to produce water. An even more far-reaching approach is filtering and purifying body fluids to act as an interim water supply, should extreme conditions arise.

Several technologies must be pursued to provide portable, organic power sources. For example, methods to extract power from the hydrogen compounds in water sources could be adapted to SORE force needs, thus doubling the benefits of having the water.

Similarly, battery packs must be more compact, lighter, rechargeable, and retain longer life on a single charge. In that light, the potential exists to create technologies that exploit human movement and central or autonomic nervous system activity as low-grade energy sources.[37] Further, since SORE forces will spend a lot of time walking, this "energy" must be harnessed and exploited. For example, "boot chargers" located in the heels of a force member's boots could be used to operate or recharge as the member performs his/her daily routines. These combinations may, in turn, be applied to battery charging to accommodate the need.

In the same vein, several energy technologies are projected which may provide alternative portable sources. They range from lightweight, solar panel collection systems, to ambient lunar light collection panels; to miniaturized power-generating factories on a single microchip.[38] The technological leaps made in solar power, as well as microscopic machines, should be investigated for SORE force application. Expedient replenishment and replacement solutions might be precision-guided delivery systems and energy weapon recharging via direct satellite link. In both cases, sensors will monitor inventory levels and track source supply points automatically and replenish as needed. The latter concept is a "passive-push" replenishment system similar to today's Just-in-Time or Trickle Charge systems. This approach minimizes administrative communications that may compromise covert or clandestine units and optimizes use of limited replenishment assets.

Move or Transportation Systems

Any special transportation requirements needed by SORE forces will likely be provided by non-SORE resources. As table 14 indicates, non-SOF, Precision Strike SOF, and/or Host-Entity resources will fulfill our movement requirements.

While these new systems will be advantageous to SORE, none are SORE-unique. Hence, SORE forces will rely on application, access, and use of collaterally developed methods to meet their transport needs. Therefore, these systems are not described in this paper. The reader can refer to the "Precision Strike," "Airlift," and "Spacelift" white papers for details.

Table 14

Move Systems' Dependency Matrix

"MOVE" SYSTEMS	SORE Source	NON-SOF Source	SOF PS Source	HOST-ENTITY Source
Av Foreign Internal Defense		X		X
Exfiltration/Infiltration Systems		X	X	X
Strap-on/Strap-off for SO Acft		X	X	

Notes

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11. ***2025*** Concept, no. 900577, "Gumping Audio and Video Library," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

12. ***2025*** Concept, no. 900501, "Artificially Intelligent Word Processor," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

13. ***2025*** Concept, no. 900263, "The All Seeing Warrior," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

14. ***2025*** Concept, no. 900280, "Fly on the Wall," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

15. ***2025*** Concept, no. 900341, "Robobugs," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

16. ***2025*** Concept, no. 900340, "Universal Language Translator," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

17. ***2025*** Concept, no. 900624, "Hand-held Translator," Concept, no. 900560, "Portable Language Translator," and Concept, no. 900607, "Universal Translator," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

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21. Ibid.

22. Ibid.

23. Ibid.

24. See *New World Vistas* study for complete definition.

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26. ***2025*** Concept, no. 900351, "Transatmospheric Reconnaissance Aircraft," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

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Appendix B

Definitions of Underlying Technologies

Central Processing Units on a Single Microchip where the power of 16 Cray YMP supercomputers will be manufactured for under $100 on a single microchip that will contain about 1 billion transistors. These will be used to create micro-mechanical devices, micromachines, microrobots, microsensors, and be integrated with microelectronics devices on a "single chip."[1]

Condensed Charge Technology "produces small, tightly bound dense clusters of electron charge of enormous power relative to their size. Integrates spark, or more accurately micro-arc discharges, into, not out of, a system thereby taking advantage of the many beneficial properties inherent to the phenomenon. It can then be made, controlled, and used on command."[2]

Data Fusion Technology whereby multivariate data from multiple sources are retried and processed as a single, unified entity. Fundamental to C^2, with Intel being a major component.[3]

Electromagnetic Communications. Development and production of a variety of telecommunications equipment used for electromagnetic transmission of information over any media. Analog or digital information ranging in bandwidth.[4]

High-Performance Computing. Development of extremely high-performance digital computers with vector and massive parallel processor architecture. Needed to process massive amounts of data in real time.[5]

Image Processing. A process that will acquire, transfer, analyze, and display real-time imagery for use in a variety of systems.[6]

Holographic Neural Technology. Software written in complex numbers (real and imaginary) using holographic principles and quantum theory, allowing information to be superimposed or enfolded by a convolution of complex vectors, requiring only one to three passes to map the desired information.[7]

Metal-Oxide Semiconductor is a microtransistor with nanometric dimensions.[8]

Molecular Nanotechnology. Building things from the bottom up. Starts with individual atoms and uses molecular-sized machines to put systems together in predetermined configurations.[9]

Nonbinary Computing[10] where speed of data computing will be increased by magnitudes of order beyond today's current standards.

Virtual Reality. Holographic full-color, three-dimensional projection where the information can be digitized and transmitted to remote locations. Will enable a person to operate complex systems from remote locations or project themselves into an artificial environment.[11] For example, "picturephones may protect the person on the other end of the line into the middle of your room as a 'light sculpture'."[12]

Wide Baseline Interferometric Synthetic Aperture Radar (SAR) Imaging. 3D dimensioning where images can contribute important data.[13]

Zero-Point Energy is the process of taking energy out of the air and converting it directly into heat or electricity with no other by-products. Zero-point energy is the ambient energy left in space after all of the heat has been removed—absolute zero. Basically, it is taking energy out of the electromagnetic fluctuations in a vacuum.[14]

Notes

1. John L. Petersen, *The Road to 2015, Profiles of the Future* (Corte Madera, Calif.: Waite Group Press, 1994), 29.

2. Ibid., 61.

3. *SPACECAST 2020, Air University into the Future* (Maxwell AFB, Ala.: Air University Press, 1995), 56.

4. Ibid.

5. Ibid., 57.

6. Ibid.

7. Petersen, 44.

8. Ibid., 29.

9. Ibid., 58.

10. ***2025*** Concept, no. 900357, "Micromechanical Devices," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

11. Petersen, 45.

12. Ibid., 62.

13. ***2025*** Concept, no. 200005, "Multiplatform Interferometry," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996) and *New World Vistas: Air and Space Power for the 21st Century*, summary volume (Washington, D.C.: USAF Scientific Advisory Board, 15 December 1995), 43.

14. Petersen, 159.

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The DIM MAK Response of Special Operations Forces to the World of 2025: Zero Tolerance/Zero Error

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Executive Summary

The United States enters the twenty-first century as the world's lone superpower. The alternate futures of 2025 propose different scenarios whereby the US face different competitors.[1] Col Jeffrey Barnett, in *Future War*, details two types of competitors the US will likely face in the next century—peer and niche.[2] A peer competitor will have technologies and weapons comparable to the US while a niche competitor will posses limited numbers of new weapons and a considerable mix of current weapons. The goals of these competitors are to control or challenge vital US, national interests. These potential competitors and the threat they pose imply that the dangers cited in the current national military strategy will still be relevant in 2025. These dangers are regional instability, proliferation of weapons of mass destruction (WMD), dangers to democracy and reform, and transnational conflicts.[3]

The authors believe special operations forces precision operations (PO) will offer senior commanders alternatives conventional forces cannot provide. SOF give the commander in 2025 a highly motivated and trained team able to respond to missions characterized by a narrow window of opportunity, low requirement for repetition, and a high consequence of failure.

What do the authors envision for the role of special operations forces in 2025? The authors define special operations missions and the concept of operations (CONOPS) for the missions, develop capabilities required to support these missions, and identify enabling technologies.

Key special operations missions will be weapons of mass destruction (WMD) neutralization, high-value target (HVT) engagement, high-value asset (HVA) recovery, and ether targeting. The WMD neutralization mission is designed to destroy or neutralize a WMD device in a target location. The HVT engagement mission will cause either a permanent or temporary effect to a person or item to achieve strategic effects. HVA recovery operations are conducted to bring sensitive items or American citizens back under US control. Ether targeting missions expose or exploit vulnerabilities in the electron medium used by either peer or niche competitors. Special operations ether targeting requires rapid and stealthy insertion and extraction of individuals. Long loiter in the target area significantly increases probability of detection and mission compromise.[4]

Key capabilities will be communications, mobility, and destruction/neutralization. These three capabilities link global awareness (communication); global reach (mobility); global power (destruction/neutralization); the selected special operations missions; and the system elements that comprise these missions. The capability of communications not only details the communications requirements of future SOF precision operations missions but addresses the need for mission

knowledge, fusion, integration, and analysis of the specialized information necessary for precision operations missions. The capability of mobility addresses the problems facing today's special operations planner such as vertical lift, global range, and high speed of current special operations lift aircraft. The capability of destruction/neutralization looks at the weapons or devices required in these missions. The paper explores the entire spectrum of weapons from nonlethal to lethal for potential application to tailor the weapon for the specific mission. This exploration includes the investigation of potential technical "weapons" kits for ether targeting missions. The system elements targeted in each of these missions are a person, item, process, or ether.

All of these missions possess unique mobility, communications, and destruction challenges. Research into the requirements for these missions revealed potential technology advances to solve today's challenges. The most promising technological solutions are in propulsion and powerplants for SO aircraft such as hypersonic aircraft; design and development of a stealth airlifter; extraction rockets; smaller, integrated, and more durable communications equipment; and tunable lethality weapons.

Notes

1. Col Joseph A. Engelbrecht, Jr., et al, "Alternate Futures for 2025: Security Planning to Avoid Surprise," draft of white paper for ***2025*** study.
2. Jeffrey R. Barnett, *Future War* (Maxwell AFB, Ala.: Air University Press, 1996), xviii.
3. President of the United States, *A National Security Strategy of Engagement and Enlargement* (Washington, D.C.: White House, 1996), 1.
4. Political sensitivity and limited opportunity require special operations competency in third wave warfare. While security, policy, doctrine, and technology for information dominance will reside in conventional or civilian domains, special operations will be the primary tool selected for eyes on target, special reconnaissance verification, and exploiting extremely limited windows of opportunity. This white paper focuses exclusively on the special operations slice of information dominance and tools required to enable this unique capability.

Chapter 1

Introduction

Victory smiles upon those who anticipate the changes in the character of war, not upon those who want to adapt themselves after the change occurs.

—Gulio Douhet
The Command of the Air

Dim Mak (or *Dim Hsueh*) is a once forbidden technique in Chinese kung fu. The literal translation is "The Poison Hand" (or "Touch of Death"). *Dim Mak*'s technique teaches to strike a vital point, with a certain force, at a certain time, and kill.

The mastery of this art requires long hours of hard training with patience, perseverance, and study. It masterfully focuses a precise strike, accounting for both position and direction, with a variable degree of power depending on the point of impact at a target. It also requires near-perfect knowledge of the enemy system, and is highly dependent on both the weather and the time of day for a successful strike. The *Dim Mak* strike provides for many levels of lethality, from paralysis to death in several hundred days.

The attributes of *Dim Mak* are mirrored in those of special operations forces in 2025. These forces will be highly dedicated, motivated, specially trained, and uniquely equipped. They will operate throughout the war and peace spectrum, but their forte will lay in missions characterized by political sensitivity, limited opportunity, and the use of unorthodox approaches. In 2025, the SOF precision operation's capability will demand a continuous stand-ready posture on a global watch and the ability, at a moment's notice, to mobilize, deploy, locate, identify, and engage specific targets. Using varying levels of effect or lethality, SOF can then withdraw and redeploy without a trace.

In deciding how to apply SOF precision operations capabilities against a particular target, the target is viewed as a system whose components can be categorized into one of the following: people, items (or hardware), processes, and ether. With the ongoing information revolution and growing dependence on information technologies, ether is becoming a lucrative environment that SOF precision operations can target. The decision of what component to target within a system must be analyzed by thoroughly understanding the desired end-state, accurately evaluating system component vulnerability, and knowing the risk to precision operations forces.

In SOF, mission failure is not an option. In the true spirit and capability of *Dim Mak*, SOF offensive operations will provide the US with an uncanny ability to defend national interests and achieve national security strategy objectives.

Assumptions

To postulate special operations force's missions, the authors used a limited number of assumptions that they generated after considering the 2025 alternate futures.[1] The assumptions, together with the alternate futures, allowed the study group to validate the need for SOF to perform four specific missions no other US forces would be capable of performing.

Competitors will still exist to challenge the US in 2025. Many of these competitors will have the same high technology systems as the US. Some states will lack the sophistication inherent in US systems and will lag behind US advances in microtechnologies,

computers, electronics, aerospace technologies, miniaturization, and robotics. The nature of the global state environment will range from poor and impoverished states to third wave, high technology states.

Nonstate actors with the power to threaten US interests will exist in 2025. These actors may include the multinational corporations, terrorist organizations, drug cartels, criminal organizations, and possibly energy or resource coalitions. Nonstate actors will be less sensitive to political influence, and economic pressure will have very little effect on their organization or operation. Consequently, military power may be the only element of national power which can control these actors. State and nonstate actors challenging US interests may emerge with an expanded technological edge over the US. These actors may appear slowly and cautiously or may come on the global scene unexpectedly.

Terrorism will be an increasing activity performed by powerless political groups. These organizations may reach a level of sophistication and begin using some forms of WMD to accomplish what the gun, rifle, and bomb did not in the twentieth century. Americans will present lucrative targets to these organizations using terrorism as US businesspeople travel the world tapping into foreign markets, exploiting natural resources, and searching for cheap labor to assemble goods. State and nonstate actors not capable of pursuing political goals through military means may use hostage taking as a means of gaining world attention and achieving limited political objectives. The US must be prepared for this eventuality.

A weapon of mass destruction is any weapon having the capability of killing at a level of magnitude much greater than conventional weapons. Today, WMD include nuclear devices and biological and chemical weapons, and in 2025 some forms of ether attack. These weapons will likely continue to proliferate; by 2025, or even well before, many of today's third world countries will be at least capable of building primitive WMD devices. Both state and nonstate actors will likely possess these weapons in 2025. Terrorists armed with these devices may extract ransom after demonstrating use and threatening future use. Irrational state actors possessing WMD and delivery capability pose the gravest threat to US interests in 2025.

The US must be able to attack selected targets which are not vulnerable to precision-guided munitions or conventional explosives. These targets may need servicing with tunable destructive weapons which limit or eliminate collateral damage. These high-value targets could be people, facilities, or electronic databases. Enemy targets, valuable to the US, will be protected by passive and active means. Deep underground bunkers and mobile targets will present the greatest challenge to US targeteers.

The information age will present many challenges to states with economies based on this technology. The spectrum of electronic medium will service both military and private sectors. The US must have the ability to react to threats in this medium in much the same manner we react to violence perpetrated by criminals and terrorists. The world of 2025 will have certain countries which have established electronic means of performing all functions performed today using paper—such as money, contracts, military orders, and designs for buildings or facilities. Protecting and penetrating this medium will be a US requirement.

Lastly, technology will not solve all tactical military problems. The need to have a human on the ground will still exist in 2025 to observe, decide, and react. Humans in the loop are required for missions having the highest risk of failure and highest consequence of failure when the level-of-success guarantee nears 100 percent. Humans will still be needed to perform these zero-failure missions. They will add the flexibility needed to react to the unexpected and succeed.

Note

1. Col Joseph A. Engelbrecht, Jr., et. al., "Alternate Futures for 2025: Security Planning to Avoid Surprise," draft of white paper for ***2025*** study.

Chapter 2

Capabilities Required and Concept of Operations

It takes farsightedness and guts to build an armed force that will only be called to fight in, say, a decade. One has to guess, as best one can, what resources will be available, what kind of opponent the force will be called on to face, and what kind of environment they will have to operate in. Those fundamental questions settled, the time comes to decide how to best meet the challenges ahead.

—Martin van Creveld
The Transformation of War

SOF in 2025, like today, will focus on high-risk, highly specialized, high-consequence-of-failure missions; and will require nearly 100 percent guarantee of success—zero tolerance/zero error. Political sensitivity is so significant that only a tailored organization with special skills, training, and equipment can accomplish these missions and assure success. The nature of the mission, size of the force required, and skills needed will dictate use of small, extremely mobile, highly trained, quick to react teams of special operators. The frequency of the requirement to use these forces, the specialized nature of their employment, the target, risk, and consequence of failure levels will require employment of these unconventional forces. Figure 2-1 provides a graphic representation of the mission area SOF precision operations will operate in. There will continue to be some missions, where the consequence of failure and mission risk are so high that a military option may not exist.

Special operations in 2025 will continue to employ the five near-timeless core

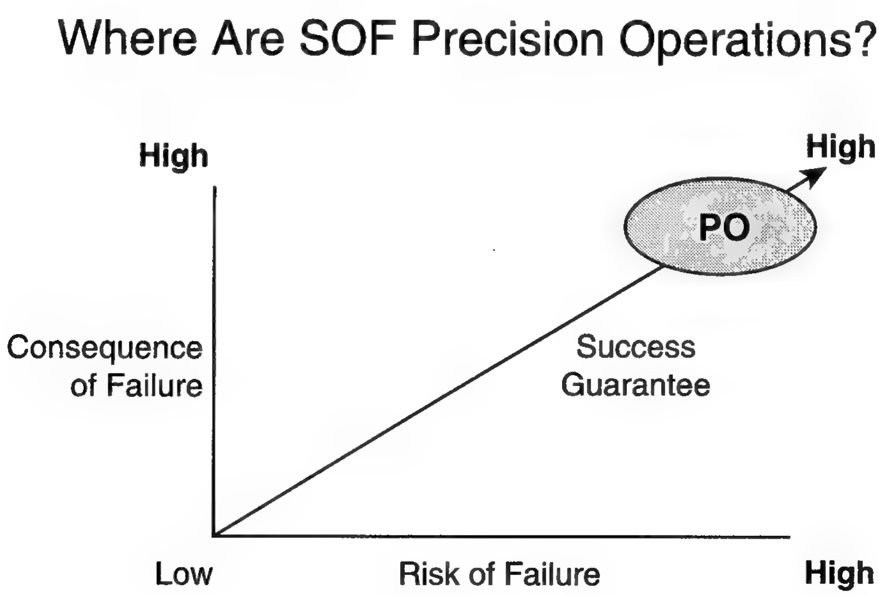


Figure 2-1. SOF Precision Operations

competencies of "unconventional training and equipment, political sensitivity, unorthodox approaches, limited opportunity, and the need for specialized intelligence" to varying degrees and will be very mission dependent.[1] These core competencies coalesce and beget the required capabilities to meet four primary mission types plausible for any possible future world of 2025: WMD neutralization, HVT engagement, HVA recovery, and ether targeting. Each of these missions will require special teams of specially equipped forces.

Weapons of Mass Destruction Neutralization

Weapons of mass destruction will continue as a reality well into the twenty-first century and as a major security concern for the US. Nations not possessing these weapons may seek the security this weapon provides. Nonstate actors and terrorists may successfully hold states hostage and achieve objectives by using these weapons once and then making demands with the threat of continued use. Irrational state actors electing to use WMD as preemptive tools may draw other states possessing these weapons into Armageddon.

These weapons will be secured through passive and active means. Deep underground bunkers and mobile launchers will make destruction of these devices difficult. Air attacks may require precision designation by SOF, with a much greater accuracy than today's capability. Several target sets may be too precariously positioned to permit self-designation by airborne platforms. It is additionally possible that precision-guided munitions and air attack, even by uninhabited aerial vehicles (UAV), may be futile against some deeply buried storage sites which are protected by early warning devices and layers of air defense weapons. Enemy ground forces will be positioned to react to intrusion and thwart direct attack by conventional means. WMD storage and launch sites will be located in distant, isolated areas which naturally make intrusion and penetration difficult. Gathering intelligence on these sites will be challenging due to cover, security, and location of these sites. Mobile launchers will be moved from site to site for protection from attack. States threatening use will have forces at high alert to protect these high-value items.

In 2025, WMD will include nuclear weapons, poor man's nukes (biological and chemical weapons), and a new "deadly" WMD—"Information Bombs" (IB).[2] Demographic and political changes described in the ***2025*** alternate futures unfortunately provide uncommonly fertile ground for Alvin Toffler's first, second, and third wave entities to execute both coherent and sporadic direct actions on the United States and its allies and friends. The purpose of these actions by aggressor nations, terrorists, organized crime cartels, or even single individuals will be to "level" the distribution of wealth and resources, power redistribution, or simple political agendas.

WMD neutralization will require locating, analyzing, penetrating, and eliminating the weapon. Neutralization may include destruction at the site, transporting to friendly control, or neutralizing critical components. Penetrating the facility will require high-fidelity, accurate, real-time intelligence. Strategic and tactical mobility to move SOF teams and neutralization equipment is also required. Eliminating security forces will require a variety of weapons—weapons which can stun, immobilize, or kill.

High-Value Target Engagement

HVT engagement seeks to obtain a wide range of options, from temporarily disabling to total destruction. Designated high-value targets would have strategic significance affecting the highest levels of an organization (i.e., multinational corporation) or state during peacetime or war. These operations could be conducted against individuals as HVT engagement operations

are tunable for a variety of results, from lethal to nonlethal. High-value targets may include command, control, communications, computer, and intelligence (C^4I) nodes, protected power generation sites, or underground command centers to facilities in close proximity to sensitive noncombatant sites such as hospitals, religious places, or schools. Both the nature of the target and the location will dictate precision operations, eliminating or minimizing collateral damage.

SOF will face many of the same challenges presented in WMD neutralization missions. Strategic and tactical mobility to and from the site is required. Some of these operations may be conducted remotely with essentially a reconnaissance team waiting for the opportunity to strike or designate the target. In those instances where a facility or deep underground facility must be penetrated, the same capabilities inherent in the WMD neutralization mission apply. SOF will still be faced with eliminating security, penetrating the target site, and applying tunable devices which manipulate the target. These devices will limit damage to what is required to achieve desired results. Tunable weapons will permit SOF operators to achieve results without producing unwanted world criticism. Precision-neutralization operations conducted against high-value targets require extreme precision, timing, coordination, and offer the added value of deniability.

High-Value Asset Recovery

HVA recovery operations return sensitive items, people, or things to US control. HVA recovery operations may also return allied citizens to their country and friendly control. Additionally, in 2025, HVAs may include financial databases, corporate trade secrets, or proprietary knowledge in Bill Gates's brain. These missions are the most difficult and must be conducted as quickly as possible. Time wasted formulating plans, preparing forces, and deciding options allows enemy forces to gain positional advantages. Precision-operations forces must safeguard sensitive items and hostages. Facilities will offer the enemy protection from direct assault. The surgical nature of these operations require sorting out enemy personnel from hostages and separating enemy personnel from sensitive items without damage to the item.

SOF will require high-fidelity, accurate real-time intelligence to penetrate these facilities successfully. Neutralizing enemy security forces without harming hostages or damaging sensitive items is of paramount importance. Tunable weapons will permit separating enemy from friendly personnel. Strategic and tactical mobility is required to move SOF from base locations to target sites. Speed, stealth, and surprise are essential requirements to successful operations. Arriving undetected at the site permits securing HVAs before the enemy can react. Transportation of team members and hostages or sensitive equipment requires both tactical and strategic mobility.

Hostile governments and organizations will pose a significant threat to the safety of American citizens. Nations, organizations, and/or individuals not possessing the adequate power to confront the US may resort to kidnapping and stealing to attain political goals.

Ether Targeting

Despite giant strides in information dominance over the intervening years, disparity between US laws and customs and those of peer or competitor entities provide fertile ground for hostile activities to contravene US vital interests. These "unfriendlies" develop special talents to circumvent both prevailing law as they become the modern-day cyber pirates.[3] They readily steal, lift, or appropriate commercial trade secrets, software, or the individual who possesses the knowledge. The market is king. US dependence on information systems, knowledge or "wisdom," and commerce will make the impact of a logic bomb or a multimorphing power virus devastating.[4]

Source: "Parachute 740-2 MMS," *Armada International*, October/November 1994, 51.

Figure 2-2. "Buddy" Jump

Drop Zone®, a movie starring Gary Busey, covered this exact scenario where the target set was a Drug Enforcement Agency (DEA) database of undercover agents. Busey, an ex-SEAL, employed precise high-altitude low-opening (HALO) jump techniques to land on the DEA headquarters in restricted airspace of Washington, D.C. He had already snatched a computer geek and taught him to jump under extreme conditions. Figure 2-2 shows a picture of this type of parachuting. With a small, carefully crafted team, Busey and team, tapped into the DEA database, downloaded the pertinent information on deep cover agents, and transferred the information to cartel chiefs for a small fee.[5]

As previously discussed, current policy for off-the-shelf contracts and information management acquisition to decrease government expenditures set the stage for easy access to critical economic and security information. Today, the manipulation and stealing of knowledge is a reality in commercial, political, and military arenas.[6] To know and control (ether *Dim Mak*) the knowledge of one's adversary is the key to success. Sun Tzu wrote, "foreknowledge must be obtained . . . all war is based on deception."[7] Special operations forces must determine when the ether problem is deception and when it is real. When directed within the ether or cyber environment, special operations will neutralize or destroy target sets outside the boundaries of conventional means.

One commercial "system" that may be a hot prospect is the idea of intellectual property.[8] Once targeted by an adversary or "snatched," special operations would employ HVA recovery techniques for the property's safe return. Preempting this scenario would require sophisticated ether identification, monitoring, and "destruction" techniques. Our adversaries are investing heavily in information manipulation. Once in this arena, special operations forces will require an "info" kitbag.

Notes

1. United States Special Operations Command, *1994 United States Special Operations Forces Posture Statement* (Washington, D.C.: GOP, 1994), 3–4.

2. ***2025*** Concept no. 900328, "Information Bomb," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996); see ***2025*** counterinformation white paper for further research on MMPVs and information bomb impacts on US vital interests.

3. Microsoft Network News, "US, Japan in Piracy Battle," Internet address: http://www.msn.com, 10 February 1996, 1845 CST, states the "music piracy dispute could become a test case for the new intellectual property rules of the 116 member WTO. . . . The US argues that under the trade-related aspects of intellectual property rights (TRIPS) agreement of the Uruguay Round world trade accord, Japan must extend copyright protection to foreign records dating back 50 years. The Geneva-based WTO covers intellectual property rights, unlike the General Agreement on Tariffs and Trade (GATT)."

4. Wieslaw Gornicki, "In the Shadow of the L-Bomb," *Warsaw Przeglad Spoleczny Dzis* (FBIS translated text—Polish officer discusses Infowar), 1 November 1995, 48–60; ***2025*** counterinformation white paper.

5. *Drop Zone*®, Paramount Pictures, 1994.

6. Microsoft Network News.

7. Sun Tzu, *The Art of War*, translated and with an introduction by Samuel B. Griffith (Oxford, England: Oxford University Press, 1971), 106 and 145.

8. Danton K. Mak, "Intellectual Property Checklist for Ventures in the 90's," on-line, Internet, 20 March 1996, available from http://www.calcom.com/sm/articles/ipcheck.html, 1.

Chapter 3

Enabling Capabilities and Supporting Technologies

This chapter performs two functions: (1) it lists and describes the requirements for each of the three capabilities introduced as essential to mission success in the four SOF missions; and (2) provides the reader with, when possible, technology solutions which satisfy each enabling capability requirement. Where research falls short or technology solutions are not provided, the team has provided possible alternatives or technology transmogrifications which might exist in the time frame of the study. The authors have carefully considered concepts of operation where they recommended specific technologies. The researcher has pointed out the potential shortcoming associated with using technologies which have a potential tactical shortcoming associated with its use, and when possible, has made recommendations to minimize the drawback.

The three essential enabling capabilities needed to successfully perform the SOF offensive missions of 2025 are communications, mobility, and destruction/neutralization. This chapter discusses each capability, lists and, where necessary, defines performance requirements, and provides technological solutions. The chapter discusses solutions subsequent to the introduction of each performance requirement. Requirement parameters are expressed using the extreme end of the requirement criteria (most demanding criteria). For example, the range to a target may vary with the mission, but this chapter uses the most demanding range to describe the performance criteria.

Communications

SOF precision operations communication requirements go significantly beyond the team members' ability to talk to each other. Communications in the context of this paper involves the quest and distribution of mission knowledge in a timely and useful manner to guarantee mission success. Mission knowledge involves intelligence (preknowledge of one's adversary or threat), real-time remote sensing, human-enhanced sensing, and finally electronic information processing, distribution, and storage systems. As noted in Alan D. Campen's book, *The First Information War*, "Because of the strategies of deception, maneuver, and speed employed by coalition forces in Desert Storm, knowledge came to rival weapons and tactics in importance."[1] The SOF precision operations teams of the future will depend on the ability to manage and dominate mission knowledge. Communications via voice, sight, touch, external sensors' inputs, and even thought will afford SOF precision operations teams of 2025 the edge to gain and maintain mission knowledge dominance over any adversary.

Several unique factors drive communication requirements for the precision operations mission. SOF communication drivers currently include the requirement for worldwide, real-time, multinet linking capability within a precision operations team, and to other command, control, communications, computer, and information (C^4I) nodes. Based on the authors' assumptions, in 2025 there will be a need for communication systems featuring clandestine and covert modes of operation; multilevel security; and the capability to integrate, fuse, and manage numerous sources of data and information. These future sources may include voice, video, sensors' inputs, navigational information, and identification friend or foe (IFF) data.

Today, this all-encompassing communication capability, "the system of systems," conceived by the former vice-chairman of

the Joint Chiefs of Staff, Adm William A. Owens, USN, is under initial development for US DOD needs.[2] New technologies in computer capabilities, digital data storage, processing, data fusion capabilities, and global positioning support this concept. This system of systems brings together battle space awareness, increased precision engagement capability, and enhanced C^4I to provide the future SOF precision operations mission the needed advantage to achieve mission objectives.

Figure 3-1, a derivative of Admiral Owens's initial idea, shows an added region to the system of systems called personnel interface.[3] A critical requirement for PO in the 2025 time frame, the personnel interface section of this system of systems identifies the unique human-interfacing requirements for precision operations. The unique personnel interface requirements are primarily driven by needs for covert operations and security during precision operations missions. Nondetectable equipment and signals will be a necessity for precision operations in 2025 especially as the threats' capability to detect and counter SOF missions will increase. Admiral Owens's system of systems must be compatible with SOF precision operations needs, and this personnel interface will ensure the requirements for these communications are identified and addressed. The term *info-kit*, also shown in figure 3-1, is a proposed name for this future system and will be used throughout this section of the SOF precision operations white paper.

The consequences of mission failure are extreme for both the SOF team members and potentially the United States. Therefore, the need for extremely reliable, durable, simple, and redundant communications is essential. Affordability will also be a driving factor for any future communication systems, and will make unilateral SOF development of precision-operations communication equipment unlikely and dependency on commercial communication markets a necessity. The rapid pace of technological developments makes the ability to develop, procure, and bring to operational status communication equipment before it becomes obsolete or vulnerable to threat countermeasures difficult and too costly for expected SOF budgets. Numerous commercial applications are being developed

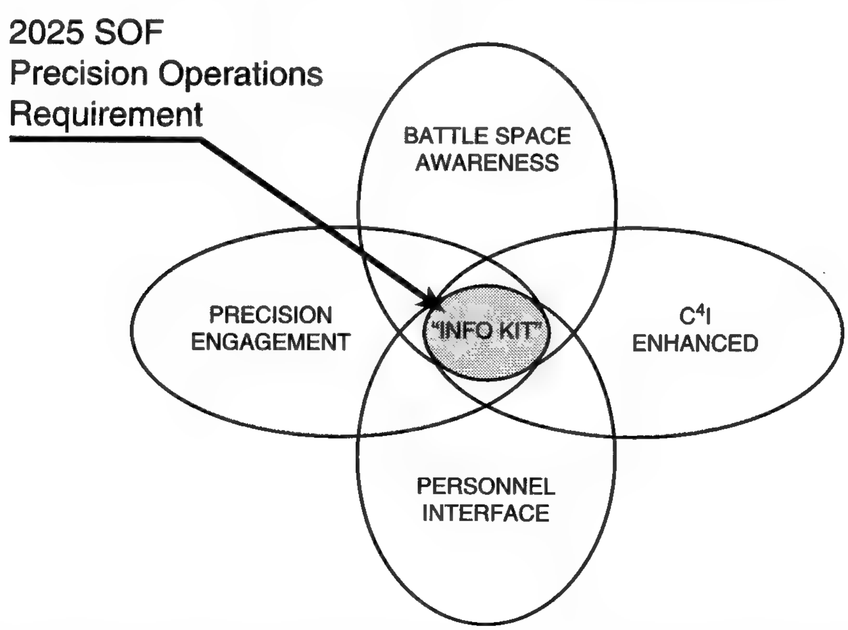


Figure 3-1. System of Systems (Modified for Precision Operations in 2025)

for secure local, regional, and global communications capabilities. The military and SOF can take advantage of this commercial development to procure required communication capability, their avoiding the initial developmental costs.

The ability to effectively communicate has always been a key component to any successful military operation. Sun Tzu identified the importance of communications during military operations when he wrote, "Drums and bells . . . flags and banners . . . must be used for troop communication in battle." Then, now, and in 2025, communications capabilities will provide SOF precision operations the necessary flexibility to achieve concentration of force, coordinated and undetected mobility, speed, precision, synergy of effort, unity of command, surprise, and ultimately the achievement of mission objectives. Communications truly is a force multiplier and one of the founding pillars supporting the fundamental principles of war.

Worldwide Communications

SOF precision operations requirements for worldwide communications will generally fall into three categories, local, theater, and global. Each category may require unique equipment for several reasons including technology limitations, diversity, and reduced complexity allowing tailoring for specific mission needs. Ideally, an all-in-one device, an "info-kit," could offer the required communication capabilities needed by SOF in 2025. Whatever technologies exist in the future, the info-kit must provide seamless communications with other DOD communication systems and provide significant interoperability with older communications equipment and systems that will be prevalent throughout the world.

Local communications would give SOF precision operations team members links between each other and with other C⁴I nodes. These SOF teams must be capable of communicating over relatively short distances up to several kilometers without detection. Additionally, SOF requires the ability to use multiple nets or channels simultaneously allowing precision-operations team subelements discrete interconnected communications. Direct communication with other military organizations and noncooperatives would also be a necessary feature. The term *noncooperative* identifies organizations or systems not willingly or knowingly communicating with the SOF precision operations team. Supporting airpower requirements for the local precision operations communication may include the use of prepositioned uninhabited aerial vehicles. UAVs may provide communication relays between local precision operations teams, other military forces in the local area, or relays to other theater and global C^4I networks. These flying relay stations would be deployed singularly or in constellations as necessary for each mission and be withdrawn at mission completion.[4]

The next two categories for SOF precision operations communications are theater and global. These categories would entail the ability to communicate with a diverse array of command and control nodes and mission support systems such as remote and nationally controlled sensors and transportation assets. During a recent lecture at the Air Force's Air Command and Staff College (ACSC), Col John A. Warden III, USAF, Retired, provided the potential of future C^4I:

> During the initial strikes on Baghdad in January 1991, part of the air campaign planning staff sat around their TV sets in Washington DC watching for indications on CNN *Headline News* about the attack success on one of their first target priorities that night, Baghdad's electrical power grid. Shortly after 1900 EST (0300 in Baghdad), a CNN correspondent team reported live from Baghdad indicated the city lights started going out.[5]

Colonel Warden additionally described that some Scud missile-launch warnings were being provided to in-theater target areas via relays through US-based command and control nodes.

Similar to the two events described above, a diverse real-time global communication capability would allow for critical mission

information and decision making to take place anywhere in the chain of command. Decisions could be made or mission results could be viewed in real time at National Command Authorities (NCA), commander in chief (CINC), or joint force commander (JFC) levels, if necessary. The sensitivity of future precision operations missions may not permit a final mission decision until the SOF team is engaged at the mission objective or target site. For example, the neutralization of a rogue nuclear device may include several options—device removal, device destruction, or device manipulation to give the appearance of operability though inoperable. The final decision concerning disposition of the device may not be realized until actual events develop during execution and on-scene mission environmental factors are evaluated. Global communications will allow final mission decisions at the regional CINC, JFC, or NCA level. In this scenario, a worldwide communication capability has provided additional flexibility to the mission by allowing the mission execution decision to be made at the highest level if needed, and at the latest possible moment. Other solutions, such as ongoing negotiations, would have an extended chance to resolve the crisis.

Supporting technologies for regional and global communications include the use of high-altitude UAVs and space-based satellite communications relay and processing systems similar to the advanced military satellite communications (MILSATCOM) concept offering significant increase in capability of today's MILSATCOM systems.[6] The advanced MILSATCOM will offer global, secure, personalized, high-data-rate communication capability. Another ***2025*** concept applicable for worldwide communications suggests the capability of faster-than-light, infinite distance communications via "quantum polarization shift of shared photons."[7] This capability would revolutionize communication and mission knowledge dominance as we know it today. Finally, the technology to transmit, receive, and process very high data-flow rates, on the order of terra-bits per second, is a future requirement for all worldwide communications capabilities.

Clandestine Operations

The requirement for PS teams to operate covertly drives the need for any future SOF communications to operate with low probability of intercept or detection (LPI/LPD). Two general approaches to this solution are identified. First, develop a communication system with signals that are undetectable by the threat. This can be accomplished in a number of ways, including the use of very low-power transmitters, but this may limit equipment effective range. A smart info-kit system of the future may allow for real-time adaptive power modulation techniques that use only the minimum required power to accomplish the data transmission. Another approach to making precision operations communications undetectable would be to develop a system that operates outside the normal energy patterns for typical or expected communication bandwidths. Today, a majority of military communications occur in the very high frequency (VHF) bandwidth, generally in the area of 30 to 500 MHz. Undoubtedly, future military communication systems will expand to cover a much wider spectrum. Currently, developments in the 1.5 GHz bandwidth is ongoing with the potential to expand significantly higher or lower.[8] Whatever communication systems exist in 2025, the ability to operate on the fringes or outside the normal energy bandwidths could provide the needed surreptitiousness inherent in precision operations.

The second approach to LPI/LPD communications for precision operations teams of the future would be to make such equipment and associated signals blend into the surrounding environment. Currently, nearly every country in the world today is experiencing a communication evolution. Some estimates predict that by the year 2000, up to 80 percent of worldwide telecommunications will be wireless.[9] Mobile telecommunications are expanding rapidly throughout the world,

especially in many developing countries where land phone and data lines do not exist. Cellular-based systems for voice and data communications using microwave radio networks are becoming common throughout the world. They afford a developing nation the "quick connect" to a diverse local and worldwide communication network. Additionally, future developments in wireless technologies will provide the popular local area network (LAN) systems, prevalent throughout the industrial world of today, a wireless capability.[10] Over the next several decades the atmosphere will be "buzzing" with numerous signals from these developing wireless capabilities. The ability for SOF precision operations communications to blend into this noisy environment may be less of a challenge than trying to avoid detection and provide another means for covert communications.

Any attempt to lower detection levels through LPI/LPD communications in the future will most likely require a combination of techniques. No one solution will fit all scenarios or requirements for precision operations' stealthy communication. The design of these future communication systems must be adaptive and capable of operations in many future world environments.

The next concern for SOF precision operations with regard to covert communications deals with the visibility or recognition of the communication equipment. Potential precision operations scenarios may require the SOF team to blend into the local populous and surrounding environments. Personnel hauling a communication kit with antennas, a cumbersome battery pack, and headsets will be very conspicuous and therefore a lower probability of success should be expected. The capability to miniaturize and hide communication equipment is essential.

Under the charge of the US Army Communications Electronic Command (CECOM), the 21st Century Land Warrior Program is developing and field testing an individual soldier computer/radio kit.[11] This kit is expected to weigh approximately two pounds and strap onto the soldier of the twenty-first century providing voice, data, and imagery to each soldier and throughout the chain of command This system is expected to greatly enhance the overall effectiveness of Army combatant units. Though two pounds of equipment does not sound cumbersome by today's standard, the packaging of this equipment will not meet precision-operations team requirements. Team communications equipment will need to be light, mobile, and unrecognizable as a communication system. Miniaturization should allow communication and supporting equipment to be imbedded into mission apparel or uniforms. Interfacing with the equipment could be through implanted ear and throat pieces. Contact lenses could be the display screens of tomorrow affording normal fields of view. These lenses could display necessary visual data for mission tasking and additionally act as sensors for data collection or enhancing as night vision goggles do today. Controls for such equipment must also be unrecognizable and activated through gestures, voice, touch, or even thought control. Whatever communication technologies develop in the future, the precision operations team will most likely need equipment that is unrecognizable as such for mission accomplishment.

Advances in electrical and mechanical microminiaturization technologies will be needed to package the info-kit of 2025 into a usable precision operations system. Additionally, communication equipment power supplies often make up a large percentage of the total system volume and weight. Power supplies for the info-kit of 2025 will need to be inconspicuous, durable, and highly mobile. A ***2025*** concept suggests the use of human body heat as a potential energy source.[12]

Communication Security

Secure communications will be required for SOF precision operations missions not only within the precision operations team but also with other related activities. These missions may proceed or occur simultaneously with other combatant operations. Being able to communicate securely with

other operations will be crucial. The need for multilevel encryption capability will be required in the future and is currently being developed by CECOM in their digital integrated laboratories.[13] Currently, separate networks are needed for different levels of classified communication. To be compatible and capable of communicating with different operations apart from the precision operations team, a multilevel security unit that allows the commingling of data with different security classifications will be needed. Interoperability will be needed not only with other DOD communication equipment but with other secure nets to include those operated by other nations' military forces and noncooperative systems described earlier.

The info-kit of 2025 may afford an adversary a tremendous advantage should it fall into his hands. Therefore, operation of such a system must be protected and could be easily accomplished by deoxyribonucleic acid (DNA) tagging specific equipment to individuals or groups of individuals. When the DNA tag is lost, so is the info-kit's capability. Additionally, data storage areas within the info-kit would be self-destroying after a preset time of lost user DNA signature.

Data Fusion

The next aspect to discuss for SOF precision operations communications involves the capability of future systems to integrate, process, and provide numerous sources of information to the precision operations team member. Admiral Owens's system of systems now in the conceptual design and initial technology demonstration phase will evolve into an operational system in the early part of the twenty-first century. In the time frame of 2025, this system will undoubtedly be more capable and functional for SOF precision operations requirements. Today, new technologies are allowing the fusing of multiple communication and information data into one multipurpose device. Advances in computer software, data storage, and processing speed capabilities along with microminiaturization advances will allow for the combination and integration of many data sources for precision operations. Numerous informational data source (NIDS) processing capability will greatly enhance the future SOF operations. A part of the info-kit, NIDS processing would combine real-time voice, video, external sensor data, global position location and navigation, IFF information, and any other system deemed necessary in 2025.

External or remote sensor inputs to the NIDS systems could range from those at the national asset level such as space-based multispectrum satellites, theater-level UAV inputs, to local preposition or on-body sensors such as the Advanced Research Project Agency (ARPA) concept being developed to detect toxic substances. ARPA is working on a "neuron-based biosensor that can feature nerve cells growing directly on microchips capable of sensing toxic substances."[14] ***2025*** concepts such as "I Can Smell You, "and "Fly on the Wall" are ideas for local sensors that can be propositioned for a PO mission and provide vital real-time mission data directly to a NIDS type-system.[15]

Other subcomponents to the NIDS system could include an individual monitoring system (IMS) capable of evaluating, and if necessary, administrating immediate life-sustaining medication to the system user. For HVA recovery missions where hostage rescue is the objective, the NIDS could incorporate another subcomponent called Medical Emergency Reaction Instructions or MERIT guidance for self-administered emergency medical treatment to injured hostages or other SOF team members. When activated, the MERIT system would help remotely diagnose and instruct the necessary medical treatments, similar to the medical tricorder seen in Paramount's *Star Trek®* TV and movie series. Through the development and use of artificial intelligence computer capability, the NIDS system would provide the user with the right information at the right time to enhance situational awareness, sustain life, and guarantee mission success.

Communication requirements for SOF precision operations in 2025 will involve much more than just the ability to talk to team members. Technology is affording the future precision operations team member the capacity to achieve knowledge-space-dominance needed for 2025 tasks and missions. Admiral Owens's system of systems will likely be in its third or forth technology evolution by 2025. Combining many of the emerging and developing ether technologies will provide situational awareness to SOF precision operations, guaranteeing mission success. By identifying SOF precision operations communication requirements now, the evolution of the system of systems will be the info-kit in 2025. This capability for SOF to achieve knowledge-space-dominance over an adversary will ensure the US is capable of achieving its national objectives in 2025.

Mobility

Mobility is one of the three enabling capabilities for special operations in 2025. It plays a key role in each of the missions envisioned—WMD neutralization, HVA recovery, HVT engagement, and ether targeting. This section details systems attributes and required technological advances to support these systems. Mobility, as defined for this study, is the system or systems that provide SOF insertion and extraction capability for a designated mission. This study will not address any additional mobility requirements for the teams after initial insertion, only the strategic and tactical systems for insertion and extraction. The team has identified three potential mobility systems satisfying special operations 2025 mobility requirements, a stealth airlifter, low earth orbiter (LEO), and exfiltration rockets. The mobility systems directly affect the enemy processes in the sense that the insertion and extraction location, method, and route planning will impact enemy command and control efforts to counter the mission. Additionally, mobility has a direct impact within all facets of the HVA recovery mission due to the payload requirements for the people or things to be recovered. The enemy will dictate target locations; therefore, SOF must possess an infinite range of insertion and extraction capabilities. This will enable special operations teams to operate throughout the enemy system processes to conduct WMD neutralization, HVT engagement, HVA recovery, and ether targeting missions. Though mobility requirements exist across the full spectrum of SOF missions, table 1 illustrates the most critical aspects (shaded areas) between the SOF missions and enemy system elements with relation to their mobility requirements (i.e., a critical SOF mobility focus for HVA recovery is on personnel and/or human characteristics).

Current special operations lift platforms will not survive third and fourth wave competitors in 2025. Emerging technologies can modify and enhance existing platforms increasing their performance, but to increase the probability of mission success, a new special operations aircraft is needed. To obtain vertical lift capability in current lift platforms, a large trade-off in speed, payload capabilities, and range is accepted. Analysis reveals that by 2025 this need not be the case because of technological advances in areas of lift platforms, powerplant and propulsion systems, and aircraft rotorblade improvements.

Stealth Airlifter

A primary lift system to accomplish this could be a stealth airlifter.[16] A stealth airlifter is needed because surprise is critical to success in SOF precision operations. Primary attributes that need to be incorporated into the stealth airlifter are low observability, high speed, long range, global reach, increased payload, reliability, and durability. This new airlifter should also possess vertical takeoff and landing (VTOL), armament, and an array of emission support sensors. Experts estimate that a special operations stealth airlifter could be fielded in adequate numbers with these capabilities in 20 years.[17] An artist's

Table 1
Relationship of Systems to SOF Missions (Mobility)

	People	Item	Process	Ether
WMD Neutralize			Critical	
HVT Engagement			Critical	
HVA Recovery	Critical	Critical	Critical	
Ether Targeting				

conception of a potential special operations stealth airlifter is the MC-X (fig. 3-2), based on a current study undertaken by the USAF to be completed in 1997. The primary focus of the study is infrared (IR) and radar cross section, and powerplant and propulsion systems for airlifters.[18]

A value-added feature might be to incorporate a pilotless function to the stealth airlifter. This feature would reduce the number of personnel at risk and allow for a smaller craft, thus reducing the radar cross section of the platform. This feature is expanded from a concept in *New World Vistas*, "Aircraft and Propulsion" volume, depicting an unmanned fighter-type aircraft.[19] This platform could be adapted to house a special operations team in the payload bay for insertion. The precision navigation and targeting capabilities on board offer the JFC an option he does not now possess.

Another lift platform offering promise is a ***2025*** concept suggesting a modular medium lift aircraft.[20] This aircraft will employ low-observable technology, large cargo capacity, internal engines, and possess a

Source: ©McDonnell Douglas, "Commando Spirit" Concept Photo.

Figure 3-2. MC-X

6,000 nautical mile (NM) unrefueled range. A benefit of this concept is the platform can be manufactured in the modular level and have several different models with comparable characteristics: airlifter, tanker, global range strike, and the special operations version. This concept saves time and eliminates the requirement to invest precious research and development dollars to develop a purely special operations lift platform.

Technological advances also offer promise in powerplant and propulsion systems. National Aeronautics and Space Administration (NASA), working in conjunction with aircraft manufacturers, has invested heavily in aircraft engine technology.[21] One effort having a direct military application is a Mach 4 civil transport with reduced nitrogen oxides emissions, and quieter engines. An additional area offering promise is the use of magnetic-based rotation of ionized air as a substitute for physical turbine blades.[22] Powerplant experts in the *New World Vistas* predict that modern adaptive control methods to engines may yield improvements of 10 percent in the near future.[23] If successful, these technological improvements could give the NCA or a JFC the ability to quickly react to trouble spots with a highly trained team.

A final area of technological solutions to aircraft problems could be the use of eclectic materials in the construction of aircraft rotor blades. Eclectic materials must be rigid enough to withstand effects of flight but be malleable enough to enable changes in shape during operation. Use of these materials will permit airfoils to adjust shape during flight—improving lift, reducing drag, and resulting in increased performance.[24] Retrofitting existing aircraft with this technology will deliver an increase in performance potentially eliminating a need to design and develop a new aircraft.

Low Earth Orbiter

A second potential lift system for SOF in 2025 could be a low earth orbiter (LEO). This platform would be able to deliver the two-to-four-man teams anywhere in the world with a precision landing. The LEO gives the JFC the ability to respond quicker than airlift platforms; however, thermal reentry signatures detectable by competitor threat detection systems must be overcome.

Technological advances in hypersonic vehicles research and study has increased the potential of this platform for special operations use. A promising vehicle in planning would fly at hypersonic speeds and be able to deliver a payload in 10 minutes.[25] The team would be housed in the payload compartment and released for a precision landing at the desired location. While this system is primarily designed as a weapon, the payload could be designed to house the special operations team with its associated equipment. Precision delivery of the payload, such as a circular error probable (CEP) of under 100 feet, is vital to this system. Special operations missions often entail night insertion and the teams must be able to begin their mission quickly after arrival. Dispersed teams needing to regroup or identify their exact location run the risk of compromising mission success. To achieve this level of accuracy, the aerial delivery system (ADS) must continue to be improved. Advances in parachute, guided parafoil, and deployable wing systems offer promise in improving the ADS capability.[26] Integrating these advancements with improved Global Positioning System (GPS) and onboard navigation systems, and digital ground mapping will enable payload delivery with pinpoint accuracy. It is estimated that reusable launch vehicles, if developed in conjunction with NASA, could be available in 10 years using rocket propulsion and 25 years using air-breathing propulsion.[27] A great deal of investment in fuels, propulsion, ceramics, and other technologies must be undertaken to make this a reality.

Additional hypersonic platforms in research at this time are rapid response/global reach aircraft system and space launch/support

system.[28] The rapid response/global reach aircraft system is projected to fly at speeds greater than Mach 8 with global reach. The space launch/support system proposes a reusable launch vehicle (RLV) that could deliver a payload in orbit on short notice and return to base. If payload pods could be produced, the teams could be inserted from space from this vehicle. This concept would emulate the delivery profile of the troops in Robert Heinlein's science fiction novel *Starship Troopers*.[29] In this novel, military forces are loaded into capsules to be ejected from the spaceship. Once through the atmosphere, parachutes are employed to brake the descent until landing.

Extraction Rockets

A solution to the vertical lift extraction problem may exist in the extraction rocket. The SOF team has taken an idea from the *New World Vistas* and used it for extraction, not delivery.[30] This system would be inserted with the special operations team, be easy to set up and launch from field conditions, and have a payload capacity large enough for the team plus extra cargo. If necessary, the rockets could be hidden with chameleon camouflage during mission execution and then used when needed.[31] The extraction payload could be a WMD device or a HVA item. Use of this system will allow a team and payload to quickly exit the target location. This is critical for special operations, since the longer the team remains in the mission area, the greater the chance they may be captured or killed.

Another option for extraction could be a jet-pack device the team member would strap on his back. This device would transport the member to a safe haven for extraction by airlift or to loiter for an aerial recovery.

The extraction rocket would possess the following attributes: speeds in excess of Mach 1; air refuelable; long range; payload capacity large enough for a two-to-four-man team and a WMD device or HVA item; high durability; and precision delivery. An additional possibility for the extraction rocket would be to launch the team into a low orbit and the team would be recovered in space. This would eliminate the long-range and precision delivery requirements. The extraction rocket would boost the crew into space and await the arrival of an RLV to return the team to earth.

The jet pack would need to lift at least 500 pounds and transport the member up to 100NM. This would enable the special operations team to depart the target area and deploy to a safe haven for extraction. An alternative would be a deployable balloon connected to a cable to allow for aerial recovery of the member. Incorporated in the jet pack would be an emission-control sensor suite to reduce the signature of the member as he flies. Additional features could be a jet-pack suit the member would wear, which incorporates low-observable technology, is armored, and has a programmable navigation system. These features would allow the member to climb into the suit, program the navigation system, and sit back as he is delivered to the desired location. This would be an especially attractive feature if the member is injured and unable to pilot the jet pack himself or if the HVA to be extracted can not operate the controls. The propulsion system must be very quiet to avoid detection but still provide high speed to allow the team to quickly exit the target area.

Technological advances offer promise to solve many of the challenges facing future SOF planners. The trade-offs required for vertical lift in speed, range, and payload, and other critical requirements such as secrecy, security, long range, and speed can be solved by technology. Specifically, advances in stealth and propulsion and powerplant systems will allow the development of stealth airlifters and hypersonic aircraft dedicated to the SO mission.

Destruction/Neutralization

As in the past, special operations forces in 2025 will be required to apply force to accomplish national strategic objectives. In the future, such an offensive application of force will be categorized into two types of

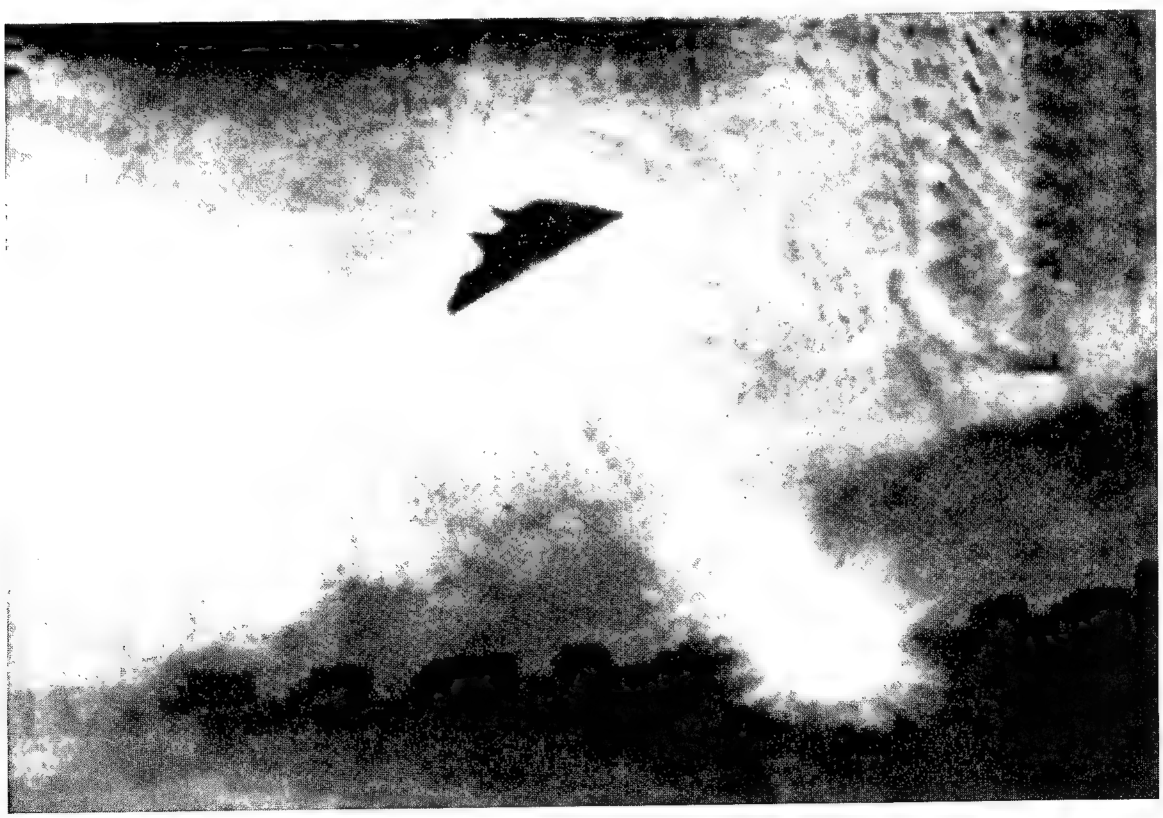
engagement: destruction and neutralization. Each type of engagement will also house several levels of lethality. As is the case today, Twenty-first century capability must include the ability to conduct such engagement with a high degree of certainty with minimal risk of compromise. However, unlike today, 2025 requirements will include the necessity to operate not only within all three of Toffler's waves of global social development, but possibly within a new wave yet to be projected.[32]

Table 2 graphically depicts that selected SOF precision operations missions in 2025 will have a requirement to destroy or neutralize, with varying degrees of lethality, an enemy system's parts. Though requirements will exist across the mission spectrum, for SOF in 2025, emphasis on the five system elements, shaded and marked as critical, provide a nice cross section of capabilities.

WMD Neutralization (Targeting Items)

WMD resources require the host government provide the best available security or protection and control. Specially trained and specifically focused forces are needed to successfully engage within this arena. Special operations forces will require an in-depth knowledge base and high-tech equipment to effectively target this threat.

It is not feasible to have all special operations team members be combinations of nuclear physicists, biochemical professors, computer science specialists, munitions disposal experts, and special operations specialists. Technology in 2025 will allow teams to carry with them this level of expertise. Within 30 years, virtual systems



Source: ©McDonnell Douglas, "Commando Dagger" Concept Photo.

Figure 3-3. MA-X

Table 2
Relationship of Systems to SOF Missions (Destruction/Neutralization)

	People	Item	Process	Ether
WMD Neutralize		Critical		
HVT Manipulate	Critical	Critical		
HVA Recovery			Critical	
Ether Targeting				Critical

will become less cumbersome, more miniaturized, more concealable, as well as more capable. The capability to wear virtual sunglasses or contact lenses will be commonplace, very similar to technology creatively displayed in William Shatner's futurist novel and film series *Tek War*®.[33] Special operations will require that this technology develop further into a seamless two-way heads-up display system with a direct link, to the source experts located elsewhere who can provide the appropriate technical data and procedures to perform the neutralization task.

Nuclear weapons will remain a formidable resource within a government's WMD arsenal, but biological and chemical weapons will be easy to produce and afford, and will provide the most difficult challenge. WMD capability is presently measured categorically by payload, speed, and range, but in the future, this measure will be more appropriately quantified by controlled distance, measurable effectiveness, and loiter time (linger time and half-life). If SOF are to be successful in neutralizing the WMD threat, they must be capable of operating with complete control of these measurable variations.

To adequately neutralize a WMD, on-site special operations forces will be required to either physically destroy the resource, render the destructive element unusable, render the delivery system unusable, or limit the effectiveness of the destructive element. Physical destruction of the resource or delivery systems poses no additional requirements on SOF than any other engagement of a HVT. These requirements will be developed and discussed later in the HVT engagement section. However, if the neutralization of the threat requires hands-on manipulation of the system, then several other requirements will exist.

SOF precision operations equipment must possess the capability to encompass and quarantine the WMD system and apply a technology to accelerate its decay, while maintaining the outward appearance and weapons system functional integrity. This, of course, secures SOF from discovery, and the antagonist will be operating under the false pretense of a whole-system WMD capability. Any technology that could operate from outside the delivery system housing, perform the decay, and never require direct tampering, would be the optimum.

Surgically removing the agent container mechanism from its weapons system housing provides the simplest form of extraction but depends on knowledge of the system. More crude systems may provide more difficult scenarios where friendly exposure is highly probable. Future development of the immune warrior may make the risk of addressing this type of threat more acceptable.[34] It has been stated that, "by the year 2000, 15 percent to 20 percent blood doping will be proven to provide up to 25 percent enhancement of a soldier's performance in a variety of environments."[35] Taking that next step in

human manipulation as common practice, by 2025 nearly 100 percent protection to selective agents should be a reality.

Even if selective immunity for precision-operations team personnel neared 100 percent, the creation of a miniaturized, self-contained, translucent biosphere which will hermetically wrap as a flexible bubble around the weapon system, to protect the operations environment is necessary. Included within the bubble will be tools to neutralize the weapon through dismantling, injection, or exposure of the core to a chemical or biological antiagent. Sun simulators or other light-spectrum decayers can be applied from outside.

A final requirement of SOF within the WMD realm, which leans towards a precision operation, will be to either insert a WMD into an enemy's arsenal for activation or utilize an indigenous weapon and create a controlled accident scenario for the enemy to deal with. This will require the finest remote operations capability available for activation, so as not to injure special operations forces. This technology should also include a self-destructing system to avoid any discovery of tampering after the fact.

HVT Engagement (Targeting Items)

Precision operations revolve around providing precision access to difficult high-value target sets. Special operations engagement of these HVTs can take many forms, but the two to be discussed presently are within a designation role and a sniper role. These two roles promote distance from the target and nondetectability. These, of course, do not relieve SOF from the possible requirement to get dirty in a target area planting next generation explosives, with varying levels of destruction on-site. However, future deceptive technologies such as chameleon camouflage and deceptive holographic imaging would assist SOF in nondetectability.[36] Of course, these technologies would not become a mission show-stopper, because special operations members in 2025 will continue to be highly versed in the art of concealment and evasion, and always will fall back on their naked-man skills. Additionally, a special operations designation team requires the capability to designate a target, but not be actively tied to a designation system. The capability is needed to place an undetectable emitter on a target from a distance, which emits continuously (or with a minor decaying rate) within a spectrum received by the guided or homing weapons of 2025.

The tactical designation ranges for present-day laser systems provide a respectable standoff distance from the target. In the future, SOF would still, depending on the mission parameters, appreciate that separation capability for illumination. Beam emissions need to be modified by 2025 to allow self-emitting beam riders to follow the designation stream and attach themselves to the target, similar to a particle beam without the impacting force.

Expanding on a paint tag ID system, a technique could be derived to develop a form of clear paint which maintains a phosphorescent capability in the electrooptical spectrum, which remains in visible to the naked eye and has a slow decay rate.[37] Additional options for pinpoint designation would be to optimize nanotechnology and develop a ROBOBUG, a fly on the wall, or some form of nanotech emitter to proceed or be placed on a target's desired mean point of impact (DMPI) awaiting signal capture by an air system with an adequate weapons payload.[38] These guided weapons—either missile, bomb, or direct beam—must all have the capability to home in on the emission signal.

HVT Engagement (Targeting People)

Some scenarios will not allow for the convenience of outside weapons systems to provide the form of kill. The special operations sniper team must also possess the capability to properly identify (ID) the target, designate the target (if needed for internal systems), and provide the appropriate kill mechanism to manipulate

the target. The term *kill* implies the completeness or finality of the engagement action, with varying levels of lethality, and does not imply the literal definition of death.

The Hollywood movie, *Runaway*®, with Tom Selleck provides an interesting form of projectile for development.[39] It is fired from a hand-held weapon, resembling a gun, but houses homing missiles with an individual DNA signature applied. Fired within the sensor range of the target, the missile goes active. The missiles could also contain varying levels of solid or liquid explosive. Of course, the movie targeted humans, but this system could be tied to any of the other designators already discussed and applied to targeting items.

Star Trek the Next Generation®, episode 157, called "The Vengeance Factor," showed an interesting form of targeting people which may become a SOF precision operations tool for 2025. The story involves a planet with a history of clan wars, and one clan developed a bio-virus that would only affect a certain clan of people. The developing clan was not directly affected, but could carry the virus, nearly undetected within their own bloodstream. Merely a touch to anyone of the enemy clan caused death.[40] The possibility of a SOF precision operations team, being able to infiltrate into an enemy target area, apply a predetermined or tunable level of lethality to enemy personnel simply by touch, would minimize the need for additional support equipment and weapons—thus, allowing the forces to blend into the cultural environment.

In all precision situations, the question of level of destruction is very important. Weapons systems either carried in by SOF to perform the destructive task or an external application targeted via special operations designation must have the capability to be controlled and/or varied in theater or via communications enroute. Focused blasts, yield variations, penetration with time-delay fuzing, genetic homing, and many others will give the SOF specialists the on-the-spot targeting capability for a given situation. Development of a universal explosive, which by appropriate shaping and form of detonation, may provide for many different styles of explosions with varying levels of destruction "Doing the right amount of damage, to the right thing, at the right time."

HVA Recovery (Targeting the System Process)

Within the high-value asset recovery mission, only two overlying capabilities exist due to the inherent possibility of human-to-human confrontation—identification of friend or Foe and Self-Protection. Technologies in 2025 will operate in the nanosecond regime between functions, leading to a quicker output to SOF for decision making. A special operations team should have the capability to walk into a roomful of individuals, and within a split second neutralize all the bandits, sort all the bogeys (presenting appropriate decision making data to all precision operations team members), and exclude all the friendlies. Primary use for this capability would be in hostage rescue.

To provide this level of coverage requires advances in two areas, first the sensory/display area and then the fire control/weapons system. The sensory array could be tuned for target ID via DNA sensing, or possibly a form of pheromone sensing like that of precovert target marking, or as simple as those individuals with weapons are bad and all others require further forms of interrogation.[41] These sensory inputs could then be filtered and combined with other team-gathered information, near instantaneously, and displayed within the visor of an ultimate warrior targeting helmet or a modified tactical information display helmet (fig. 3-4).[42] Of course, the sensory/targeting system must operate in all light conditions and weather environments. The targeting data then is instantly fed to a handheld slaved weapons system which will appropriately target the captors.

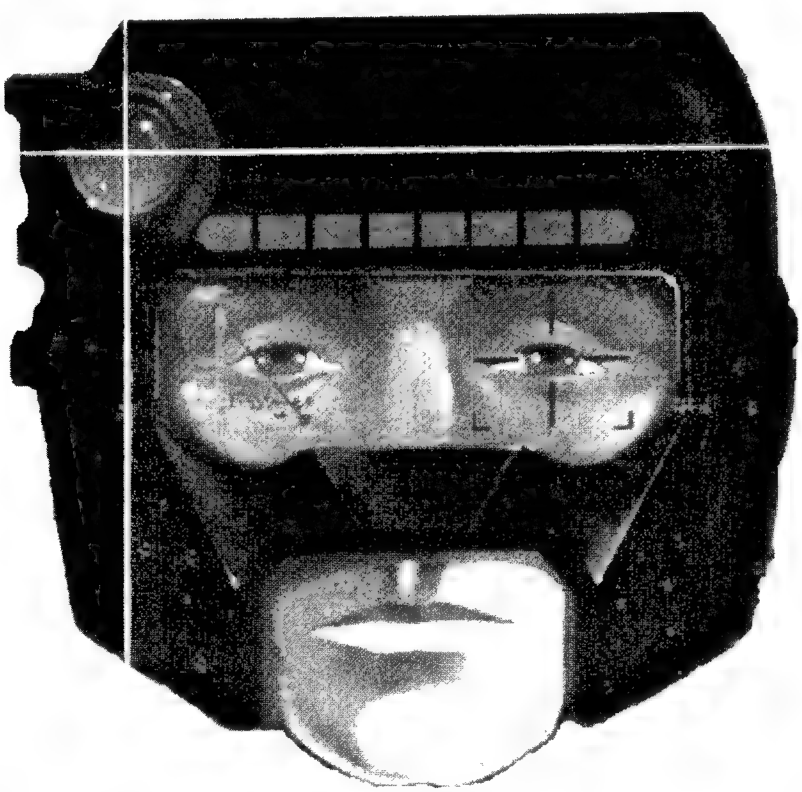
As with these offensive improvements, the defense requires equal development. The need exists to sport a self-protection field which repels all forms of forceful attack and photo-reactively counters all biological and chemical weapons. The most impressive futuristic body armor which may have merit within the next 30 years was displayed in the Hollywood movie *Dune®*.[43] This system provided a form of overpressure envelopment-force field garb which would repel reactively any fast-moving projectile, while still allowing for any slow-movement action such as touching and picking up items to continue normally.

Additionally, any form of calmative agent that could be employed prior to engagement limiting the amount of resistance, such as an amiability agent or delayed action agent, and possibly providing a passive, nonconfrontational extraction, would be welcomely employed by SOF.[44]

Ether Targeting (Ether)

Sting sings, "If you want to keep something precious, you gotta lock it up and throw away the key."[45] Information experts appear to nod sagaciously at this theory for securing databases. This may not work. While most invasive information dominance procedures can be done remotely, in some cases, SOF employment will be driven by an eyes-on-target as special reconnaissance or validation for systems impenetrable by conventional means.[46]

The ether targeting environment also drives needs for peculiar skills and equipment. Specifically, adversaries will certainly avail themselves of high-fidelity sniffers and sensors to detect net invasion.



Source: ©Litton, "Litton Night Vision" GSA Direct Advertisement, *Armed Forces Journal International*, July 1995, 12.

Figure 3-4. Future Targeting Helmet Design

By 2025, electrons will be as identifiable as DNA strands allowing individuals to detect, identify, and target particular transmissions for manipulation. Unlike most warfare, cyberwar and commercial war open Pandora's box—defining truth.[47] This peculiar problem defines the unique requirement for special operations vice conventional or civilian remote expertise. SOF will get in close enough to personally verify and validate what the computer expert sees on his monitor. The level of threats in cyberwar will dictate absolute confidence in the input source and adversary motives before punitive action is taken, either overtly or covertly.

A strong emphasis remains on high-fidelity intelligence, real-time intelligence, personnel selection, training, and limited communications along with rapid mobility of personnel, equipment, and neutralization device. If the special operations cyber team is interdicting a commercial piracy ring duping music, videos, or software packages, they will need unprecedented interagency and international authority cooperation. If the team is targeting an individual or network and wishes to preserve deniability, they may plant a specialized ether weapon such as an undetectable antidote that corrupts on system start-up. This antidote would be encased in a low-profile briefcase and transmit electronically up to several meters.[48]

Advances in electron recognition systems enable the special operations cyber warrior to monitor ether lines of communication and perform a variety of missions. One would be nulling the gateway to unfriendlies—information is sent, but stops at the gateway. It can disappear, spin into delay, receive a small parasite virus, or have minimal changes which corrupt perceived reality but defy detection.

Countercountermeasures for ether targeting are remarkably similar to aircraft systems. To perform *any* ether or cyber tasks, the warrior will require (1) ether IFF; (2) better analytical tools to determine cyber centers of gravity; (3) feedback loops with infinitesimal precision by current standards; (4) low probability of intercept/low probability of detection for ether weapons and monitoring devices; and finally (5) ether detection avoidance systems or threat avoidance systems as the unfriendlies will be equally diligent and capable in ether targeting techniques.

For ether targeting within commercial warfare, SOF precision operations will require a different array of capabilities. In a business-suit briefcase set, the SOF warrior stands out like a sore thumb. He is ill-equipped today to glide effortlessly in the halls of high finance and intrigue. Yet, US national security defined by trade secrets and corporate knowledge determines both US power and vulnerability in both foreign and domestic markets. Only political sensitivity and limited opportunity would prompt SOF precision operations engagement.

SOF hyper teams would target and deny commercial lines of communication to those who do not comply with US rules of engagement. In these cases, centers of gravity would be critical nodes such as gateways, undersea fiber optic cables, or other system links. The key for SOF precision strikes is effects-based targeting that denies the target use by foes and retain their use for friends.

Accomplishing these objectives will require delivery platforms, very high fidelity intelligence, multilevel security interagency and international coordination tools, and effective feedback loops or measurement tools to determine point of cutoff or access denied.

Notes

1. Alan D. Campen, *The First Information War* (Fairfax, Va.: AFCEA International Press, 1992), x.

2. *Warfighting Vision 2010, A Framework for Change*, Joint Warfighting Center Doctrine Division, Ft Monroe, Va., 1 August 1995, 10.

3. Ibid. The original system of systems does not contain the 4th area called personnel interface.

4. ***2025*** Concept no. 900604, "UAV Constellations," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

5. Col John A. Warden III, USAF, Retired, lecture to the 1996 ACSC class, 8 April 1996. During the Persian

Gulf War, Colonel Warden was assigned to Checkmate in the Pentagon, a unique directorate in Air Force Plans chartered to provide independent thinking and analysis on important combat-employment issues.

6. ***2025*** Concept no. 200004, "Advanced MILSATCOM Capability," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996) (PROPRIETARY).

7. ***2025*** Concept no. 900291 "Quantum Polarization Shift Communications," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

8. Braunberg, Andrew C. "Advances Push Communications Toward Army's Lowest Echelons," *Signal*, November 1995, 30.

9. USAF Scientific Advisory Board, "New World Vistas: Air and Space Power for the 21st Century" (unpublished draft, the information technology volume, 15 December 1995), 20.

10. Ibid.

11. Braunberg, Andrew C. "Advances Push Communications toward Army's Lowest Echelons," *Signal*, November 1995, 27.

12. ***2025*** Concept no. 900123, "Body Heat as a Low Grade Energy Source," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

13. Ibid.

14. Braunberg, Andrew C. "Technology Agency Aims for High Payoff Systems," *Signal*, December 1995, 29.

15. ***2025*** Concept no. 900567, "I Can Smell You," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996); and ***2025*** Concept no. 900280, "Fly on the Wall," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

16. "New World Vistas" (unpublished draft, the mobility volume), 22.

17. "New World Vistas" (unpublished draft, the aircraft and propulsion volume), 41.

18. Vincent P. Grimes, "New Ships, Plane Upgrades Enhance Special Operations Punch," *National Defense*, December 1995, 31.

19. Ibid., 10.

20. ***2025*** Concept no. 200017, "Modular Medium Lift Aircraft," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

21. John L. Petersen, *The Road to 2015, Profiles of the Future* (Corte Madera, Calif.: Waite Group Press, 1994), 172.

22. ***2025*** Concept, no. 900130, "Use of Magnetic Based Rotation of Ionized Air," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

23. *New World Vistas*, summary volume, 30.

24. ***2025*** Concept, no. 900144, "Use of Eclectic Materials in Aircraft Rotorblades," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

25. "New World Vistas" (unpublished draft, the aircraft and propulsion volume), 41.

26. "New World Vistas" (unpublished draft, the mobility volume), 22.

27. "New World Vistas" (unpublished draft, the aircraft and propulsion volume), 41.

28. Ibid., 16–17.

29. Robert A. Heinlein, *Starship Troopers* (New York: The Berkley Publishing Group, 1959), 8–12.

30. Ibid., 20–21.

31. ***2025*** Concept, no. 900699, "Chameleon Camouflage," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

32. Alvin and Heidi Toffler, *War and Anti-War* (New York: Warner Books, 1993).

33. *Tek War*®, Atlantis Productions, 1994.

34. ***2025*** Concept no. 900262, "Immune Warrior," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

35. John L. Peterson, *The Road to 2015, Profiles of the Future*, appendix B, 347.

36. ***2025*** Concept no. 900699, "Chameleon Camouflage," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996); and ***2025*** Concept no. 900570, "Deceptive Holographic Imaging," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

37. ***2025*** Concept no. 900532, "Paint Tag ID System," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

38. ***2025*** Concept no. 900341, "ROBOBUGS," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996); and ***2025*** Concept no. 900280, "Fly on the Wall," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

39. *Runaway*®, TriStar Productions, 1984.

40. *Star Trek: The Next Generation*®, "The Vengeance Factor," episode 157, 1989.

41. ***2025*** Concept no. 900375, "Target ID via DNA Sensing," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996) and ***2025*** Concept no. 900468, "Covert Target Marking," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

42. ULTIMATE WARRIOR Concept Submission, R. Colvert, *Technology Initiatives Game 95*, 38-1 through 38-2; and ***2025*** Concept no. 900317, "Tactical Information Display Helmet," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

43. *Dune*®, De Laurentis Productions, 1984.

44. ***2025*** Concept no. 900688, "Amiability Agent," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996); and ***2025*** Concept no. 900330, "Delayed Action Agents," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

45. Sting, "If You Love Somebody Set Them Free," *Fields of Gold*, A&M Records, 1994.

46. Again, this mission is not the sole purview of special operations. Commercial vendors, law enforcement agencies, and government will all strive to meet the growing threat with both individual and collective efforts. However, both cyberwar and commercial war activities will require special operations intervention—to protect political sensitivity and exploit limited opportunity.

47. Gornicki (previously cited) takes exception with Col Jeffrey Jones, former psychological operations unit commander who states, "Truth is our best weapon." Gornicki rebuts by invoking Socrates who "long ago complained about the difficulty defining truth," 6.

48. Discussion with Scientific Advisory Board Chair, Dr Gene McCall, during the ***2025*** advisors meeting at Maxwell AFB, Ala., 26 March 1996. Dr McCall indicated a belief that SOF required a unique kitbag of equipment for ether, cyber, or commercial targeting and neutralization. This kitbag or toolkit should be impervious to all mediums (i.e., submersible in water up to 100 meters or more or pressurization tolerant), relatively nondescript such as a briefcase, and possess a robust capability for density penetration or communication. While several concepts address conventional information dominance tools, they do not explore the realm inhabited by special operations. Dr McCall agreed this required further study.

Chapter 4

Conclusion and Investigation Recommendations

The time frame of 2025 will continue to be challenging for special operations forces and their precision operations missions. All alternate futures identified by ***2025*** research require SOF. In particular, SOF precision operations will provide the flexible deterrence and engagement options needed by tomorrow's political and military leaders to ensure US national security and national interests are safeguarded. In the true spirit and capability of *Dim Mak*, the precision operations capability in 2025 will mandate a continuous stand-ready global posture and the ability to instantaneously mobilize, deploy, locate, identify, and engage a target. Using varying levels of effect or lethality, precision operations teams can then withdraw, and redeploy with no trace or evidence of their being or the operation. As identified in the beginning of this white paper, special operations precision operation forces will need to be highly dedicated, motivated, specially trained, and uniquely equipped. They will operate throughout the war and peace spectrum, but their niche will lay in missions characterized by political sensitivity, with limited windows of opportunity, and the use of unorthodox approaches.

Though each of the 2025 alternate futures worlds (Gulliver's Travails, King Khan, Zaibatsu, Digital Cacophony, Crossroads 2015, and Halfs and Half-Naughts) possess unique characteristics, several variables remain constant. These are proliferation of WMD, the increase in terrorism, and the rapidly expanding worldwide interconnectivity and interdependency on ether technologies. Facets of US national interests, such as defense, economy, politics, environment, and communications, along with the developing global community are becoming more reliant on the electronic data manipulation. With this ongoing information revolution and growing dependency on information technologies, ether is becoming a lucrative environment that SOF precision operations can target.

In choosing how to apply SOF precision operations capabilities in 2025 against a particular threat, the threat must be viewed as a system whose components (people, hardware, processes, and ether) can be selectively targeted for desired effect by SOF. The enabling capabilities for 2025 precision operations identified in this white paper are communications, mobility, and destruction/neutralization. These three capabilities provide the bridge between the global awareness—communication, global reach—mobility, global power—destruction/neutralization, and will continue to in 2025.

The exact mission or missions for SOF precision operations in 2025 are impossible to predict. However, the core competencies of SOF precision operations will most likely not vary far from the present; and these competencies drive the need for specific capabilities generic to any likely future precision operations tasking. Specific recommendations for generic capability follow.

Communications

Communication requirements for SOF precision operations goes significantly beyond the ability of team members to talk to each other. Communications involves the quest and distribution of mission knowledge in a timely and useful manner to guarantee mission success. The development of the system-of-systems suggested by Admiral Owens is a foundation for the info-kit of 2025. Fusing numerous information and data sources into a usable format that is interoperable for all future worldwide

communication systems is essential. Though all ***2025*** alternate future worlds will require SOF to interact with ether systems, the Digital Cacophony future will require a distinctive edge in communication capability because one's adversary will most likely be very capable of information manipulation too.

Providing this communications capability in an inconspicuous package defines the personnel interface requirements for precision operations and the system-of-systems for 2025. Key technologies will be data compression, fusion, and transfer capabilities and new advances in software or artificial intelligence techniques to manage, manipulate, and process required data. The right information at the right time will be crucial for SOF precision operations in 2025.

Global networking with multilevel security access will be needed to meet precision operations requirements. Robust, hardened, and diverse satellite and UAV constellations would provide this global communication capability if developed and available for SOF in 2025. Additionally, microminaturization of mechanical and electronic equipment will be needed for clandestine operations. Robust but inconspicuous power supplies will also need further advances to satisfy SOF precision operations clandestine requirements.

Mobility

Mobility remains a key to special operations in any of the envisioned futures of 2025, from the peer competitor of Khan to the niche competitors in Gulliver's Travails. Regardless of the environment, insertion and extraction of SOF poses challenges that emerging technology can solve. The following areas offer suggested recommendations for investment of technology dollars to solve those challenges by 2025: stealth airlifter, hypersonic aircraft and low earth orbiters, and extraction rockets.

Current airlifters will not be survivable in 2025. A stealth airlifter will offer greater potential for mission success due to the incorporation of current and ongoing research and development in both low-observable and powerplant and propulsion systems. Investment in these areas will allow the production of lift platforms that meet critical special operations requirements of vertical lift, long range, high speed, and payload.

In a volatile world there is often a requirement to respond quickly to a given situation. Special operations missions are characterized by a very narrow window of opportunity for mission success. Hypersonic aircraft and LEOs offer the potential of inserting SOF into crisis areas quickly. Ongoing research and development in powerplant and propulsion systems will offer the potential for production of platforms suitable for special operations.

The extraction portion of special operations missions is a critical time for mission success. The requirement to exit the target area quickly is paramount. An extraction rocket could offer a potential solution to this problem. A rocket secured at the insertion point could quickly extract the SOF team out of the target area for recovery by LEOs in space or by aerial recovery systems. Extracting the team for recovery into space or utilizing aerial recovery would shorten the range requirements of the rockets reducing the size of the vehicle.

Destruction/Neutralization

All phases of the precision operations mission are critical, however, once the precision operations team is engaged with the target, how the target is manipulated is critical not only for desired effect but in the protection of political sensitivity and if need be, deniability. The insurmountable consequence of failure also drives the do or action phase of SOF precision operations to an extreme level of capability and reliability. Second chances are not viable options. To this end, recommendations for each of the four mission areas will be addressed.

WMD neutralization includes advances in the immune warrior concept, selective immunities to biological and chemical

agents; and advances in technology to accelerate decay of chem/bio agents or partial neutralization to render the destruction element or limit its effectiveness.

HVT engagement involves development of designation or tagging systems that operate within different emission spectrums. These tags would incorporate a low chance of adversary detection, self-destruction, and pinpoint location of the tagged item. HVT engagement will also provide for tunable lethality explosive technology, to select on-location the appropriate level of kill for the given target set, environment, and scenario.

HVA recovery will have advances toward an integrated tactical sensory/display/targeting helmet or info-kit as described in the communications section. This equipment would be capable of sorting out friend or foe, provide real-time communication and data links between all team members and external sensors, and incorporate direct weapon slaving and targeting links for handheld weapons. HVA recovery will also have handheld weapons systems with tunable lethality, with near-instantaneous changing between levels from stun to paralysis to death.

Ether targeting is the key to effective SOF precision operations targeting in either cyber war or commercial warfare and can preserve political deniability, exploit a very narrow window of opportunity, and support withdrawal. Capabilities and technologies to accomplish this mission are partially found in the communication section of this paper. The precision operations team's ability to interact and thus manipulate information of noncooperatives lies in the capabilities envisioned with the info-kit of 2025. Other ***2025*** research papers discuss actual techniques and equipment to manipulate or destroy an adversary's electronic data. This arena will not come naturally to a SOF hunter/killer team. These skills will seem more than foreign and alien, only in the magnitude of the threat and inability of civilian agencies to meet that threat will SOF reluctantly heed the call.

Above all, the decision of what component to target within a system must be analyzed by thoroughly understanding the desired end-state, accurate evaluation of system component vulnerability, and the risk to precision operations forces.

Appendix A

Scenario #1

In 2025, it is highly likely that nations possessing WMDs will also have sophisticated means of detecting and directing reaction forces. In all probability, WMDs will be guarded by both human and remote sensors or systems. Addressing the remote sensors will be accomplished by electronic disruption and/or deception. As a result of such efforts, electronic confusion and diversion will convince the enemy that attacks are in progress at other locations while full-spectrum jamming and broadcasts allow SOF freedom of movement for short but adequate periods of time. The use of molecular altering devices and/or chemical/biological reversing agents will allow SOF teams to neutralize WMDs, leaving the weapons system intact and preventing the enemy from knowing the weapons are harmless.

When necessary, SOF teams employed against an array of WMD sites for simultaneous destruction operations will be linked together for coordinated action through satellite communications display devices. Through a heads-up display inside the helmet, this capability will permit the operator to see actions at various sites or locations on demand, and allow operators to communicate with other operators regardless of distance or terrain. Space-based command and control centers will provide both communications connectivity between operators and command direction when required. The need for secure, digitized over-the-horizon, long-distance communications between operators and control centers is absolute. Communications mediums will have both secure voice as well as secure imaging capabilities.

WMDs which must be transported from site locations and require manpower in the absence of mechanical devices will be moved by biomechanical human enhancement devices. A man capable of lifting 200 pounds will be capable, through the use of exoskeleton devices, of lifting 500 pounds. Superhuman strength will be achieved through chemical injection and biomechanical devices. Climbing, lifting, and physical exertion tasks will be accomplished by enhancing human attributes through the use of these drugs and devices. These technologies, in addition to lightweight ceramic armored body shells, will turn the SOF operator into a formidable foe.

Appendix B

Scenario #2

Because of political as well as ethical reasons, equipment and techniques used for destruction and neutralization missions will require a level of sophistication that results in minimal to no collateral damage, as well as secrecy. Target areas identified for operations will be visually fixed in a way which allows for continuous monitoring via the fusion of information gathered by space-based and all other information-gathering platforms and methods. Such fusion will provide the user (team and NCA) with information dominance within the objective area. Once this dominance is achieved (including secure communications), teams will be inserted into a region via stealthy LEO spacecraft (referred to earlier) from which they will infiltrate by foot to the objective site. Once at the site, teams will emplace systems which will provide continuous, secure, on-site video and BDA systems for postattack analysis and real-time observation by the NCA or appropriate command authority.

Upon completion of the tasks mentioned above, teams will mark targets for engagement by using advanced laser designation systems or other systems which place permanent emitters on the target tuned to a specific frequency or infrared (IR) pattern identifiable only to the team and missile or system chosen for engagement. During this process the team will select the appropriate type of system to engage the target and transmit the information via secure SATCOM methods so that the appropriate delivery platform can be made available. The selection of the engagement system will be determined based on such things as the location and construction of the target, security, and defensive systems protecting the target, flight path obstacles, engagement angles, and civilian locations. Platforms chosen to deliver the required weapons system will be allocated by higher authority based on such items as platform location, time of flight, availability, and risk of compromise. While there may be exceptions to the rule, in most situations, teams will be extracted prior to target engagement. Engagement will be conducted using precision-guidance weapons launched from platforms well outside territorial air, land, and sea space.

Appendix C

Scenario #3

Firsthand experience developing an unclassified local and wide-area network for special operations in the late 1980s and early 1990s illuminated the potential of ether targeting in the future. Sitting at a desk in Washington, D.C., my computer would crash. I could call the system administrator at Hurlburt Field, Florida, who would dial into my computer and "see" what was happening. Within limits, he or she accomplished real-time trouble-shooting, blasted patches or software upgrades, and I'd be back in business.[1] If I sent E-mail, he could watch it clear respective gateways until reaching its destination in seconds. However, occasionally I would have to confirm what was really happening on the monitor when it did not correspond to data on his screen. The lesson learned was that with the root password and proper training, anyone could dial into my system and watch while I worked. The second lesson learned was that the military will not be able to select the personnel to design or maintain our communications, computers, or command and control networks once the military establishment shifts totally to off-the-shelf (OTS) acquisition.

People unfriendly to the United States will probably exploit this dependence on the commercial sector. Winn Schwartau provides a provocative quote from Lester Thurow:

> History is clear. While military power can sometimes outlast economic power for centuries, eventually it depends upon having a successful economic base. America's success in the Gulf War proves that it is, and will be, a military superpower in the century to come. But its success in the Gulf in no way guarantees that it will be an economic superpower in the twenty-first century.[2]

Our economic base is both the source of our strength and the primary target of our foes. "The knowledge and beliefs of decision makers are the Achilles' heel of hierarchies."[3] As our decision makers depend on the US industrial base to research develop, and maintain their metasystems (complex and interconnected galactic spider webs), we observe the creation of a weak link—the vulnerability to cyberwar.

Toffler describes a second vulnerability during an interview with Peter Schwartz for Wired magazine in 1995. "The thesis (of *War and AntiWar*) is very simple. The way you make war is the way you make wealth. If you change the way you make wealth, you inevitably change the way you make war."[4] Toffler contends that making wealth in the twenty-first century is a complete reversal of the industrial age mass production, marketing, investments, and trade. Instead, third wave economic and information warfare will center on microtrade/capital/markets/technologies and microweaponry. This is more than mere miniaturization of existing force. Mass production begat mass destruction, or

> industrialized warfare. And if we are now in the process of transforming the way we create wealth, from the industrial to the informational, or call it whatever you wish, there is a parallel change taking place with warfare, of which the Gulf War gives only the palest, palest little hint. The transition actually started back in the late-1970s, early-1980s, to a new form of warfare based on information superiority. It mirrors the way the economy has become information-dependent.[5]

The density and redundancy of metasystems defy targeting. Yet, within the military lies a vulnerability:

> As the Pentagon becomes ever-more dependent on high tech, it finds itself deeper and deeper in a maze:
>
> - It is developing a new cyberspace warfare strategy that is intended both to defend and wreck the very computer networks that support it and all other modern armed forces.

- Military officials acknowledge that they have no ability to protect themselves from cyberspace attacks and no legal or political authority to protect commercial phone lines, the electrical power grid and vast, vital databases against hackers, saboteurs and terrorists.[6]

Individuals with questionable agendas can now fulfill Toffler's prophecy of a one man, one-niche market, one-weapon threat. This drives the requirement for an equally potent countercapability.

Special operations must confirm or deny input and output of economy, security, or knowledge information systems before application of force. Just seeing it on your screen or tracing the electrons back to a source may not be sufficient verification of hostile intent. In this case, seeing is not believing. In developing a counter capability, we need to understand the environment. Col Richard Szafranski effectively narrowed the ether target set for special operations in "A Theory of Information Warfare":

> Warfare is the set of all lethal and nonlethal activities undertaken to subdue the hostile will of an adversary or enemy. In this sense, warfare is not synonymous with "war." . . . Warfare is hostile activity directed against an adversary or enemy. Information warfare is a form of conflict that attacks information systems directly as a means to attack adversary knowledge or beliefs . . . netwar or cyberwar.[7]

If the adversary is attacking knowledge or beliefs through ether means, special operations tasks may be to confirm the hostile nature of the activity. Special operations will confirm that what you see IS what you get.

Thus, both the US education system and Wall Street provide targets of opportunity for an enterprising foe. Planting seeds early for fruition down the road, applications at defense contractor facilities will contain impeccable credentials from the finest institutions of learning. But, everyone working for the defense industry will not possess hostile intent.

Special operations ability to act decisively in politically sensitive situations with limited opportunity require specialized enabling capabilities in cyber or commercial warfare. At a recent nonlethal weapons conference held in Washington, D. C., Lt Gen Lloyd ("Fig") Newton, assistant vice-chief of staff of the Air Force and former USSOCOM/J-3, "introduced information warfare and the use of electronic warfare . . . (and) establishment of appropriate rules of engagement . . . the requirement for seamless integration of lethal and nonlethal weapons."[8] Special operations conducted in cyberwar and commercial war require tools to complement and seamlessly interface with both civilian and conventional primes as a force multiplier.

Notes

1. ARINC's Software Reusability Group (SRG) patented a procedure for simultaneously updating widely dispersed networks and dubbed it "blast."
2. Quoted in Winn Schwartau, *Information Warfare* (New York: Thunder's Mouth Press, 1994), 38.
3. Col Richard Szafranski, USAF, "A Theory of Information Warfare: Preparing for 2020." Culled from the Internet off the worldwide web, IASIW homepage, 1996. On-line, Internet, 20 March 1996, available from http://www.psycom.net/iwar.1.html.
4. Kevin Kelly, "Shock Wave (Anti) Warrior," *Wired*. On-line, Internet, 20 March 1996, available from http://www.hotwired.com/wired/1.5/features/toffler.html. 1995.
5. Ibid.
6. Neil Munro, "The Pentagon's New Nightmare: An Electronic Pearl Harbor: A Look at the On-Line Frontier," *The Washington Post*, 16 July 1995.
7. Col Richard Szafranski, USAF, "A Theory of Information Warfare: Preparing for 2020." Culled from the Internet off the worldwide web, IASIW homepage, 1996. On-line, Internet, 20 March 1996, available from http://www.psycom.net/iwar.1.html.
8. John Alexander, "Nonlethal Weapons: The Requirements," unpublished article documenting the March 1996 DOD Conference on Nonlethal Weapons—accepted by Jane's IDR for publication. Used by permission.

Appendix D

Supporting Technologies Abstracts

Advanced MILSATCOM Capability (AF 2025 Concept #200004)

The advantages of future MILSATCOM systems will affect virtually all Air Force mission categories to include SOF precision operations. With the ability to securely transmit and receive large amounts of data in near-real-time, and employ fully interactive communications, significant advances in precision operations effectiveness can be expected.

Amiability Agent (AF 2025 Concept #900668)

This agent causes those individuals contacted to become very easily persuadable. This could become quite useful in hostage negotiations, providing a quick and peaceful defusing of the situation.

Body Heat as a Low Grade Energy Source (AF 2025 Concept #900123)

This capability would eliminate or reduce the need for separate battery power units for low energy consumption communication gear carried personally.

Chameleon Camouflage (AF 2025 Concept #900699)

The goal is to develop camouflage paint or uniforms that can change color to blend with the surrounding terrain. Tiny sensors and nanotech electronic devices provide the color-change capability. Color changes are provided to help minimize visibility, but could also be adapted for work in the near-visual spectrum, masking IR signature or other emissions. Advantages include the reduced preparation for deployment with no need to modify current camouflage schemes.

Covert Target Marking (Using Bug B.O.) (AF 2025 Concept #900468)

Making use of a pheromone-imitating substance or device to mark HVTs, exit trails, and extraction points for SOF. With a target marked, a new form of guidance kit must be developed to home in on this signature. Targets could, additionally, be marked well in advance depending on the persistence of the pheromone and weather conditions.

Deceptive Holographic Imaging (AF 2025 Concept #900570)

This concept calls for the development of the capability to project an array of holographic images about certain locations. The intent is to deceive the adversary into misallocation of resources, attention, and/or effort around the present operation.

Delayed Action Agents (AF 2025 Concept #900330)

Development of a poison or nonlethal agent (e.g., sleep-inducing) that has a controlled delay time before becoming effective. Such a substance could be clandestinely introduced into the food, water, or air of the adversary. The advantage is to disable the adversary without them knowing who is responsible and allowing for uncontested SOF precision operations.

Fly on the Wall (AF 2025 Concept #900280)

Modifying the original mission of this concept from reconnaissance to a fly-to placement of itself on a target, configured to emit low energy code, allowing a homing weapon to guide in on its position. The fly requires advances in nanotechnology that would give it full mobility, flight, a large field of view, visual acuity, and optimize

the fly's bulging hex-covered eyes with simultaneous views in nearly all directions. The fly would be operated via remote control by on-site special operations personnel to the DMPI, providing near-pinpoint targeting accuracy.

I Can Smell You (AF 2025 Concept #900567)

This concept proposes developing a computer chip or targeting system to detect the smell of a particular target. For precision operations, this type of device could be used in the counter WMD where once a target was detected a weapon with "smell-seeking" guidance could home in on the aroma or scent of the device.

Immune Warrior (AF 2025 Concept #900262)

By the year 2005, scientists plan to decipher the entire human genetic code, and by 2015 expectations are to have a complete DNA coding or functional definition for each of over 100,000 genes that make up a human being. The plan is to create super boosters for the human immune system, consisting of adaptive antibodies capable of responding to a wide range of pathogens from chemical or biological weapons. These super boosters will have an unlimited useful lifetime in the bloodstream and have no side effects. The special operations specialist of 2025 could selectively remain immune to any known chemical or biological agent that the enemy owned, while performing the neutralization mission.

Information Bomb (AF 2025 Concept #900328)

The commanders of adversarial forces can be paralyzed by a flood of information that SOF could directly disseminate into their computer systems, their sensors, or their satellites. This would be a controlled and timely information overload.

Modular Medium Lift Aircraft (AF 2025 Concept #200017)

Aircraft is a high-efficiency modular aircraft in the 100-ton weight class. Four comparable models are designed for airlift, tanker, global range strike, and SOF. This aircraft would employ low observable technology, provide adequate range, (6000 NM) unrefueled payload size (90kLB), and vertical lift for SOF variant.

Paint Tag Identification System (AF 2025 Concept #900532)

This concept provides a more efficient means of distinguishing between friendly and enemy platforms. The paint tag identification concept incorporates an undetectable microscopic transponder embedded in specialized, conductive paints. A low power signal is emitted from the friendly source for discerning ID, or on the targeted enemy item for destruction by a homing weapon.

Quantum Polarization Shift Communications (AF 2025 Concept #900291)

Since quantum polarization has the potential for faster than light communications at any distance and is jam proof, it would revolutionize communication as we know it today. Quantum physics has demonstrated that when two photons are emitted by a particular light source and given a unique and identical polarization, they always share the same orientation. If polarity of one photon is changed, the other photon changes its polarity instantaneously. This concept invokes the notion of subspace communication capability postulated in the Star Trek television series and would offer SOF precision operations teams tremendous capability.

ROBOBUGS (AF 2025 Concept #900341)

Same as the Fly on the Wall concept described above.

Tactical Information Display Helmet (TID-H) (AF 2025 Concept #900317)

Target sets detected by advanced battlefield sensors and other team member helmets would be data linked to all helmets. A set of targeting and recognition symbols would be projected within the SOF precision operations team member's visors, using an adaptation of helmet-mounted sight technology and virtual reality systems. Dispersed, multiaxis attacks by team members are now less susceptible to friendly fire targeting, with minimal oral communication required.

Target Identification Using DNA Sensing (AF 2025 Concept #900375)

This is the capability to identify weapons, targets, and friend or foe, through the DNA sensing technology. Each object has its own DNA fingerprint; the ability to recognize this DNA fingerprint could revolutionize target ID. An ongoing data-gathering process allows for data base growth; displays for SOF in the form of a HUD within a targeting helmet.

UAV Constellations (AF 2025 Concept #900604)

This concept would allow the deployment of several UAVs to provide radio or sensor coverage in an area of operations during a precision operations mission. If other communications systems were not available, UAVs would provide temporary or augmentation for precision operations mission tasking.

Ultimate Warrior (TIG 95 Concept)

This concept provides omnipotence in surrounding area data flow. A SOF precision operations member looks through the equivalent to a HUD; superimposed on that observation are geo-registered data, presented in visual icon form, for terrain mapping, friendly forces ID, threat positions and radii, battle plans, and communication. Added within the system could be a sophisticated targeting system, slaved to offensive and defensive weaponry.

Use of Eclectic Materials in Aircraft Rotorblades (AF 2025 Concept #900144)

Eclectic materials would permit the airfoils to adjust their shape during power on and off flight. These changes inflight would improve efficiency by improving lift, increase autorotational glide distances, reduce drag, and increase retreating blade-stall airspeeds. Primary advantages are that they can be retrofitted on current aircraft. This improvement, coupled with increase in powerplant and propulsion systems, would increase helicopter performance. A significant increase in current systems performance could negate the immediate requirement for new helicopter design.

Use of Magnetic-Based Rotation of Ionized Air (AF 2025 Concept #900130)

This concept is based on the use of magnetic-based rotation of ionized air as a substitute for physical turbine blades incremental compression of air. The advantages of this technology are that it reduces the number of moving parts and decreases the weight of the vehicle. The reduction in moving parts increases reliability rates and the reduction in weight would offer a potential increase in range and speed. All three of these factors are critical to any special operations system.

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A Hypersonic Attack Platform: The S^3 Concept

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Executive Summary

Place yourself into the future, into the world of 2025. Where will our nation be and what adversaries will we face? Possibilities include a resurgent Russia, a hostile China, or possibly a hostile Korea or Iraq. What capabilities will opposing nations have to our military? One thing is for certain, all of these possible adversaries will have access to high technology weapons. What capabilities will we need to counter these potential adversaries?

To counter these problems, we have identified three broad missions that the United States (US) military must accomplish in 2025. First, we must have the ability to deliver accurate lethal blows before or at the onset of hostilities. Second, we must be able to sustain our fighting potential without a large support infrastructure and logistical footprint. Third, we must be able to provide a routine, reliable, and flexible access-to-space capability. Based upon these three missions, we feel that our best option is the use of hypersonics.

Proposed is an integrated weapons platform approach, the S^3 concept, which would accomplish these objectives. It involves three separate, but integrated, vehicles. These include the SHAAFT (supersonic/hypersonic attack aircraft), the SHMAC (standoff hypersonic missile with attack capabilities), and the SCREMAR (space control with a reusable military aircraft). SHAAFT, SHMAC, SCREMAR (S^3) can accomplish the broad roles of Global Reach/Global Power, in-theater dominance, and access to space.

The SHAAFT is a dual stage hypersonic aircraft that fulfills future requirements for Global Reach/Global Power. It is a Mach 12 hypersonic aircraft that uses a "zero-stage" flying wing to stage at Mach 3.5. It is designed for compatible use with a hypersonic missile, the SHMAC, and a transatmospheric (TAV) orbiter, the SCREMAR. These two components combine with the SHAAFT to form the S^3 concept and allow for the fulfillment of the in-theater dominance and access to space mission requirements, respectively.

The initial goal of this study was to investigate Air Force missions that are best accomplished by hypersonic vehicles and the technology required to support them. The identification of the three broad missions to be accomplished by military forces in the year 2025 led to the need for a hypersonic weapons platform. The diversity of these missions yielded a need for different platforms with different capabilities. However, with current military budget cuts and drawdowns, development of three different weapons systems is impractical. Instead, we opted for a fresh approach based on previous studies and our own research that integrated the necessary features for accomplishment of these missions. The

result was the S^3 concept: a highly survivable, lethal integrated hypersonic weapons platform that allows the US to accomplish a diverse set of missions and is capable of deterring and/or punishing adversaries anywhere in the world.

Chapter 1

Overview of Proposed Integrated Weapons System

The clairvoyant who in 1996 gazes into a crystal ball with the intent of predicting the world of 2025 indeed faces daunting challenges. The economic, political, and military environment of the world is changing rapidly. Apparently, gone are the continued stress and tension associated with the confrontation between two superpowers. Gone also is the stability that resulted because the two superpowers developed alliances in which most of the other nation states of the world took a subservient role. Military strategists from one alliance could focus on a single adversary (or a single alliance of adversaries). Although regional military conflicts occurred, there was an absence of global conflict, since both of the superpowers recognized the substantial risks of MAD (mutually assured destruction).

Some vestiges of the cold war remain today (e.g., traditional alliances, such as the NATO alliance, continue to exist, albeit aiming for a membership expanded to include former adversaries). However, in addition to the traditional alliances, ad hoc alliances are developed in real time in response to regional conflicts, such as Operation Desert Storm, and to "internal" conflicts, such as the conflict in the Balkans. Rogue nations, no longer constrained by dependence on a superpower's military aid or financial aid, follow confrontational policies which threaten the peace and security, both of a region and of the world. Whether it is the desire of Iraq to dominate a region of the world or the desire of North Korea to develop nuclear weapons, these rogue nations are less likely to consider the downside of aggressive actions, before initiating hostilities.

While the level of economic and of political constraint diminishes, the potential for destruction grows. The military strategist of the twenty-first century can expect that most adversaries—whether a relatively traditional alliance of nation states, a rogue nation using military hostilities as a tool of national policy, or an ethnic army from a fragmented country—will have weapons of considerable destructive power, speed, and range. Many countries have nuclear weapons and other weapons of mass destruction (WMD). Theater missiles and high performance aircraft armed with sophisticated missile systems are available to all the countries of the world.

Thus, no matter what model one postulates to describe the world of 2025, it is very likely that the air and space forces of the United States (US) will have (at least) three broad roles in any conflict in 2025. They include

(1) Deliver decisive blows at the outset of hostilities, with the goal of destroying the adversary's desire to fight a protracted war.

(2) Deliver cost-effective weapons to defeat time-critical targets and to establish in-theater dominance, if a protracted war cannot be avoided.

(3) Maintain flexible, readily accomplished access to space. (As will be noted subsequently, the access-to-space missions will also be conducted during peacetime to develop operational procedures should the transition to the pace of wartime operations be necessary.)

This paper proposes an integrated multistage weapon system, which is capable of performing a variety of missions, both strategic and tactical. The design of this weapon system would be based on technologies developed during a variety of previous and of existing programs. Furthermore, the design process would include consideration of mission planning activities, base operational support requirements, and so forth.

In addition to the three broad roles described above, the air and space forces of the United States of the twenty-first century will have many other tasks to perform, including: counterair, close air support, and air lift (including humanitarian relief). However, these missions are best accomplished by other air force assets, such as the F-15, the F-16, the C-17, or their twenty-first century replacements. The proposed weapons platform is designed to be a deterrent, used at the onset of hostilities to stop the war before it begins. In short, the SHAAFT, SHMAC, SCREMAR (S^3) hypersonic weapons platform can deliver lethal blows quickly and without a large support infrastructure, is survivable with both the vehicle and the crew returning safely to their base in the continental United States (CONUS), and can provide routine, sustained access to space for a variety of scenarios.

Characterization of the Proposed Weapons System

The proposed weapons system is an integrated multistage system, which can perform all three roles defined previously, as indicated in figure 1-1. A two-stage configuration serves as the delivery system. The weapons delivery system includes (1) an unpiloted flying wing, which is used to accelerate the weapons system from the runway to a flight condition of Mach 3.5 at approximately 60,000 feet and (2) a piloted, aerodynamically efficient, attack aircraft capable of sustained hypersonic flight, known as the supersonic/hypersonic attack aircraft (SHAAFT). The SHAAFT cruises at a nominal Mach number of 12 at approximately 100,000 feet. The SHAAFT could launch either: (1) a barrage of hypersonic cruise missiles (HCM), which could deliver massive firepower to multiple targets, or (2) a transatmospheric vehicle (TAV), which is capable of delivering new satellites to orbit, repairing existing satellites, or attacking the enemy's space assets. The cruise missiles will be referred to as standoff hypersonic

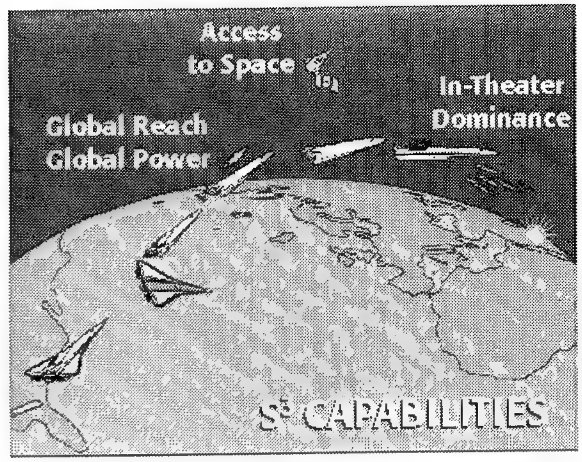

Figure 1-1. Capabilities of the S^3 Hypersonic Weapons Platform

missiles with attack capability (SHMAC) and the TAV will be part of space control with a reusable military aircraft (SCREMAR). Since the hypersonic cruise missiles have a range of over 1,000 nautical miles, the attack aircraft can stand off from the targets, minimizing the risk of losing the delivery system and its crew. Piloted and unpiloted versions of the TAV are under consideration.

Note that the SHAAFT is the only one of the four elements that definitely has a crew. For the proposed integrated multistage weapons platform, both the flying wing and the SHMAC should be designed as unpiloted aerospace vehicles (UAV). As noted in the previous paragraph, piloted and unpiloted versions of the TAV are under consideration. Thus, referring to figure 1-1, the reader can view the SHAAFT as a mobile control room wherein the personnel who deploy and control the myriad of UAVs in their arsenal are transported closer to the action. Thus, using continually updated intelligence, the crew can make better use of the unpiloted assets by modifying the mission profile in real time.

The design of the two-stage delivery system would be such that the flying wing and the SHAAFT are capable of an unrefueled flight of 14,000 nautical miles. The elimination of the refueling requirement provides many benefits. First, the operational complexity

required to support the mission is reduced. Second, by eliminating the prepositioning of tanker aircraft to refuel the weapons delivery system en route to the target, there is a considerable reduction of the communications-traffic/mission-signature that could alert the adversary of the impending mission. Third, the mission will cost less when tankers are not required. Finally, since there is no rendezvous with a tanker, it is easier to update the mission plan in response to intelligence updates. The integrated weapons system would operate from one of four bases within the CONUS, essentially one at each corner of the CONUS. By flying at hypersonic speeds, the attack aircraft (the SHAAFT) could reach any point in the world within approximately two to four hours. The exact mission duration depends on the mission routing and the exact speed range of the elements. Based on the present conceptual designs, the flying wing accomplishes the low-speed portion of the flight, from takeoff up to cruise at a Mach number of three and one-half, the SHAAFT cruises at Mach 12 at which point the SCREMAR may stage or SHMACs may be launched, and the SHMAC flies at Mach numbers up to eight.

Because there is no prepositioning of tankers to tip off the mission and because the elapsed flight time from take off from the CONUS base is relatively short, the adversary has very little response time. Furthermore, the SHAAFT operates at hypersonic speeds at high altitudes even when launching the SHMACs. Since the SHMACs, themselves, are standoff weapons with a range of over 1,000 nautical miles, the supersonic/hypersonic attack aircraft will not have to fly over heavily defended targets. Thus, it will be a very tough target for enemy defenses. The combination of hypersonic flight at high altitudes with standoff weapons makes the SHAAFT very survivable. The high altitudes and speeds also make it ideal to serve as a first stage to a small TAV. Thus, the weapons system would have the ability either (1) to deliver massive firepower to targets anywhere in the world from bases in the CONUS or (2) to provide reliable, routine, flexible access to space.

Beam weapons can affect the ability of the S^3 system to successfully execute its mission. If the SHAAFT relies totally on external navigation inputs such as global positioning system (GPS) to accomplish its mission, an adversary with advanced space capabilities could attack those assets. Thus, the elements of the S^3 system should have an onboard navigation capability. Laser weapons are currently under development to provide point defense against theater missiles, such as the Scud. It is conceivable that powerful adversaries could develop beam weapons to intercept (at least some of) the incoming SHMACs. The development of the S^3 system will have to consider such possible threats to the successful execution of its mission.

Features of the Elements of the Proposed Weapons System

The Flying Wing

The flying wing serves as a zero-stage, launch platform. The use of a flying wing (incorporating many of the technologies developed for the high-speed civil transport (HSCT), to accomplish the initial acceleration of the weapons system provides many advantages, especially in relation to simplifying the design of the second-stage vehicle, the SHAAFT. For the outbound leg, the crew of the SHAAFT would pilot the mated configuration. Once staging occurs and the SHAAFT is on the way to the target, the flying wing will return to its CONUS base as a UAV. The second-stage SHAAFT can be much lighter, since it does not have to carry the considerable weight of fuel required to accelerate the vehicle to a Mach number of 3.5 and carry it to the 5,000-nautical miles point, where it stages. The landing gear assembly for the second-stage vehicle can be relatively small, since it needs only accommodate the relatively light

weight of the vehicle at the end of the mission (and the potential ferry missions to be described subsequently). Furthermore, since staging occurs at Mach 3.5, the second-stage vehicle will not need propulsion cycles that operate efficiently at low speeds. However, such a decision means that the SHAAFT will land unpowered (as does the Space Shuttle Orbiter).

Global Reach/Global Power

Based on the computations presented in the proceedings from the Wave Rider Conference and reproduced in our research, a vehicle capable of flying at Mach 12 would be capable of reaching any point on earth within two hours.[1] Furthermore, to accomplish the objective of *Global Reach, Global Power*, the secondstage vehicle should be capable of 14,000 miles of unrefueled flight at a Mach number of eight or of 12. The secondstage vehicle, a SHAAFT would be an aerothermodynamically efficient design incorporating technologies developed during the National Aerospace Plane (NASP) program and for waverider designs. The SHAAFT would deliver multiple SHMACs without slowing down. Thus, the entire mission would be accomplished at hypersonic speeds, greatly increasing the survivability of the SHAAFT and its crew. Furthermore, the SHMACs themselves would fly hypersonically to targets at a range of over 1,000 nm. Launching the SHMACs, which are HCMs, from a flight path which keeps the SHAAFT well away from heavily defended areas, further enhances the survivability of the weapons system. The ability to deliver a decisive suite of weapons to any point on earth within hours provides a permanent "presence" that does not require constant forward deployment of the United States armed forces. The short time required to execute the operation will catch the adversary by surprise before critical elements of the opponents military strategy can be deployed or protected. Potential targets for the SHAAFT/SHMAC weapons systems include the adversary's space access complex, command and control centers, and other assets critical to the conduct of warfare in the twenty-first century. It is believed that the massive, sudden, and unexpected application of force on the first day of conflict will eliminate the opponent's desire and capability to wage war.

In-Theater Dominance

In addition to serving as the weapons to be launched from the SHAAFT, the hypersonic cruise missiles would have many uses in the case of protracted hostilities. The SHMACs would be sized so that two could be carried by and launched from an F-15E or from other conventional aircraft. Because the SHMAC has a range of over 1,000 nautical miles, the F-15E would be able to remain well out of the range of most defense systems. Furthermore, the hypersonic capabilities of the SHMAC accommodate its use against time critical, moving targets (e.g., mobile launchers, tank formations, etc.). Since the SHMACs would be launched from the (conventional) carrier aircraft at high subsonic speeds at an altitude of 35,000 feet, additional power would be required to accelerate the missile to hypersonic speeds and high altitudes (i.e., essentially the initial conditions from which the SHMACs are launched from the SHAAFT). As will be discussed in chapter 3 on the design characteristics of the SHMAC, the initial acceleration from the subsonic speeds associated with a conventional aircraft launch would be accomplished by a rocket located within the dual-mode ramjet/scramjet combustor flowpath. After the rocket fuel has been expended, the rocket casing is ejected, leaving a clean flowpath.

Since the SHMAC is to be a weapon that would be launched from conventional aircraft and, therefore, to be deployed to forward bases around the world, simplicity of operations is a driving factor in the design of this weapon. The handling of cryogenic fuels under these conditions was believed to introduce undesirable operational

complexities and expense. Therefore, since the maximum Mach number associated with the use of endothermic hydrocarbon fuels is eight, that established the maximum flight Mach number for this weapon.

Access to Space

Should the objective of a very short war not be achieved, the weapons described in the previous paragraphs can play significant roles in the military strategy for a protracted war. In this case, any nation that possesses the ability to launch nuclear weapons into space poses a serious threat to the command, control, communications, and intelligence (C^3I) operations of our armed forces. A relatively small orbiter—roughly similar in size to the Black Horse or to an F-15—could replace the HCMs carried as the payload for the SHAAFT.[2] Using multistage concepts similar to the Beta[3] or the Saenger,[4] the flying wing and the SHAAFT would deliver the orbiter to efficient initial conditions for its Access-to-Space mission. The multiple-stage system would provide flexible access to space from conventional military runways, which would be a most valuable characteristic in the event that the adversary had destroyed the facilities at Cape Canaveral and at Vandenberg. Using rocket propulsion and aerodynamic forces to achieve the desired orbits, the SCREMAR would be able to place as many as three to four satellites (nominally six feet by six feet by six feet and weighing 1,000 pounds) into low earth orbit (LEO). The same TAV could also be configured to repair satellites on-orbit as well as perform sophisticated antisatellite (ASAT) missions.

Utilization of the Proposed Weapons System

The proposed integrated multistage weapons system is capable of performing a variety of missions, both strategic and tactical. Consider the scenario where an adversary threatens to invade (the threat may include nuclear blackmail) or has just invaded a neighbor state. Based on recent headlines, the adversary in this scenario could be Iraq or North Korea. Future headlines might include China or a resurgent Russia. Despite negotiations at the highest levels, the adversary shows no signs of backing down or retreating from the occupied territory. Plans are made for a mission that would strike at the key war-fighting infrastructure of the adversary. The targets include the command, control, communications, computer center(s), the space launch facilities, critical supply depots, massed formations of enemy tanks, etc. An ultimatum from the president of the United States suggests that, if the enemy does not act responsibly, massive force will be applied, suddenly and without further warning. Authority is given to plan a mission that would seriously damage the adversary's ability and will to fight.

The next day the mission is launched. One to four SHAAFT weapons systems are launched. The number depends on the size of the adversary (specifically, the number of and distance between the targets) and the operational philosophy (whether the mission objectives include total destruction of the enemy's war-fighting capabilities or merely a very strong attention-getting strike at selected targets). The range of the "zero" stage, the flying wing, allows it to take the attack aircraft approximately halfway to the target (for purposes of discussion, 5,000 nautical miles). Staging occurs at Mach 3.5 at an altitude of approximately 60,000 feet. The SHAAFT climbs to approximately 100,000 feet, where it flies at a Mach number of approximately 12. Soon after staging from the flying wing, the crew of the SHAAFT is given final instructions: continue on to the target and execute the full-scale operation, continue on to the target and execute a modified plan (change the targets or change the degree of destruction), or abort the mission altogether. The fact that the SHAAFT is a crewed vehicle provides a great deal of flexibility. Assuming that the

instructions are to continue the mission, the SHAAFT proceeds to the area where the SHMACs are to be launched. Since the SHMACs have a range of over 1,000 nautical miles, the launch point, which is 10,000 nautical miles from the SHAAFT's home base, may not even be over the hostile country. To see an example of the standoff capability of the SHAAFT/SHMAC weapon system, refer to figure 1-2. Without slowing down, the SHAAFT launches a barrage of SHMACs from a point well out of the enemy's threat zone. Since the SHAAFT does not slow from its cruise Mach number of 12, the SHMACs will decelerate to their design cruise Mach number of eight. The SHMACs themselves may strike the target or they may deploy submunitions, which further prioritize and diversify the targeting philosophy. The suite of weapons may be nuclear, conventional, or ray devices.

Having delivered massive firepower to the targets, the next consideration is the safe recovery of the SHAAFT. The optimum scenario would have the SHAAFT return to its CONUS base. However, if there is not sufficient fuel to reach the CONUS, the SHAAFT would proceed to an alternate, preselected recovery base. Depending on the mission, Hawaii or Diego Garcia seem natural selections for the non-CONUS recovery base. The recovery base will be within the 14,000 nautical miles overall mission capability of the flying wing/ SHAAFT. Once it releases the SHAAFT, the flying wing would proceed directly to Hawaii or Diego Garcia, where it would await the SHAAFT to complete its mission.

Procedures by which the SHAAFT returns safely to its CONUS base from other recovery bases, such as Diego Garcia, will be evaluated through further study. One possibility is sending a flying wing to retrieve the SHAAFT. The mated configuration would be flown home using the engines of the "zero" stage, the flying wing, and fuel added at the recovery base. Fuel and supplies would be brought to this base so that the SHAAFT could be serviced for its flight back to its home base in the CONUS. Because the technology base for the flying wing is that of the HSCT, the logistics infrastructure at the alternate recovery bases is relatively conventional.

Considerable savings can be realized through the elimination of the constant forward deployment of the more conventional forces to provide a "presence" of US armed

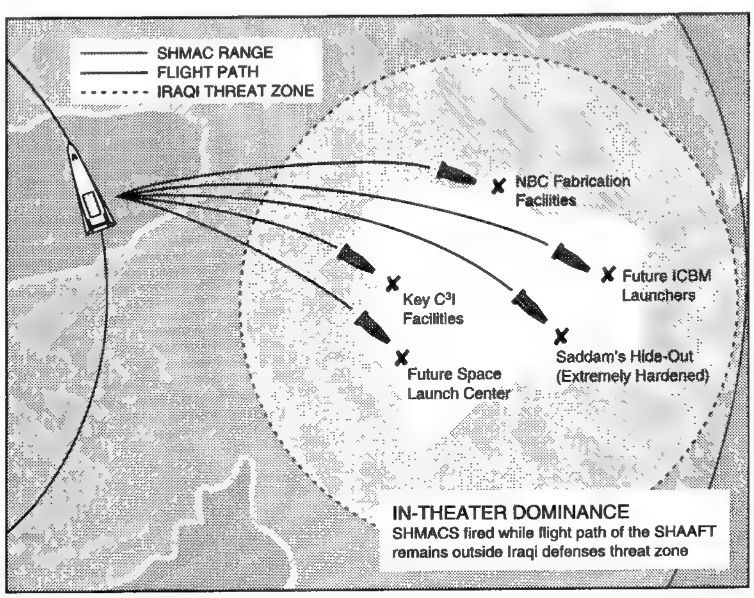

Figure 1-2. Standoff Capabilities of SHAAFT/SHMAC

forces. For those regions of the world where our forces do not have a permanent physical presence, the deployment of forces for a regional conflict is a very expensive and time-consuming project. Recall that Desert Shield took longer than Desert Storm. Furthermore, it is not likely that a future adversary will leave in place a nearby base infrastructure and then allow us the luxury of several months to build up our forces in the region. The savings described in the previous sentences could pay for most, if not all, of the design and of the development costs for the proposed, integrated hypersonic weapons system. The total fleet would consist of (approximately) five vehicles, deployed from four bases in the CONUS, two on each coast. By having an integrated weapons system strategy, the cost of the technology programs required to design and to develop the system would be greatly reduced. Furthermore, technology programs relevant to the various elements of this integrated weapons system (the flying wing, the supersonic/hypersonic attack aircraft, space control with a reusable military aircraft, and the standoff hypersonic missile with attack capability) have been in various stages of development for more than a decade.

Consider next the application, where the weapons delivery system (the flying wing and the SHAAFT) would serve as the first stage of a multistage access-to-space system. A transatmospheric vehicle would replace the SHMACs as the payload carried by the weapons delivery system. In a mission concept similar to that of the Beta System[5] or to that of the Saenger,[6] the two elements of the first stage would carry the TAV/orbiter to its launch point. Although the exact conditions for launch of the TAV/orbiter would be the subject of design trade studies, obtaining a high speed for staging appears to be more important than obtaining a high altitude.[7] Preliminary calculations indicate that the orbiter would be lighter or the payload would be greater, if staging occurred at Mach 12. Since the proposed system is to be an integrated, multipurpose weapons system, the results of the staging trade studies will influence decisions relating to the maximum velocity capabilities of the SHAAFT (in addition to the constraints placed on the SHAAFT as a result of its mission as the delivery system for the SHMACs).

It is assumed that the armed forces of the United States will have a constellation of satellites (on the order of hundreds) in place at the outbreak of hostilities. Using a variety of launch vehicles, these satellites (some large, others small) will have been placed in space over the years, as part of an evolving, strategic military strategy. However, at the outbreak of hostilities, the military leaders identify the need for additional satellites (perhaps to fill a gap in coverage, to provide additional information using special sensors, etc.) or the need to repair existing satellites. The situation becomes more critical if our adversary has disabled and/or destroyed a considerable fraction of our satellites. The armed forces of the United States have become very dependent on military/commercial satellites for communication and reconnaissance and are becoming increasingly dependent on other systems, such as GPS and Milstar. The elimination of a significant fraction of these assets by an enemy would paralyze our C^3I. Rapid replenishment of lost assets is critical to the successful execution of our military operations. The flying-wing/SHAAFT combinations take the TAV/orbiter to Mach numbers near 12 at 100,000 feet, where it stages. The TAV is a rocket-powered vehicle, approximately the size of an F-15, capable of carrying three or four small satellites (6 feet x 6 feet x 6 feet, weighing 1,000 pounds) into LEO. Thus, after a handful of missions, the country's military leaders could have a minimum of a dozen new satellites in place within days of the outbreak of hostilities. These satellites would provide communication links, intelligence information, and so forth.

It is envisioned that the flying-wing/SHAAFT/SCREMAR system would be

routinely used during peacetime to place military satellites in space, to repair and to reposition existing military satellites, and so forth. This would be done to develop mission planning and operational experience, so that our armed forces could easily shift to the wartime pace of operations in the event that hostilities cannot be avoided.

Furthermore, the TAV/orbiter of the SCREMAR could perform the ASAT role should our adversary also have significant space assets. Finally, once sufficient technology for the TAV/orbiter is developed, it could be modified to fulfill other missions: it could deliver weapons in a strategic attack on the enemy for a suborbital profile or serve as a space-based laser (SBL) or airborne laser (ABL) weapons platform.

It is quite possible that, despite the severity of the strike described in previous paragraphs, the enemy will choose to continue to fight a war. One enemy may view the conflict as a Holy War and would consider early surrender unthinkable. Another enemy may have the resources (large population and widely scattered assets) to absorb such a blow and continue the fight. A third possible scenario would be the case where the United States was confronted with two regional conflicts and the strike described above would be used to eliminate one enemy, allowing us to focus on the other. In each case, our forces are involved in a protracted war.

For the protracted war, the elements of the integrated weapons system could serve as significant elements of our arsenal. For instance, in addition to serving as the weapons to be launched from the SHAAFT, the hypersonic cruise missiles would have many uses in the case of protracted hostilities. The SHMACs would be sized so that two could be carried by and launched from an F-15E or some other conventional aircraft. Because the SHMAC has a range of over 1,000 nautical miles, the F-15E would be able to remain well out of the range of most defense systems. Furthermore, the hypersonic capabilities of the SHMAC accommodate its use against time critical, moving targets (e.g., mobile launchers, tank formations, etc.).

Indicated in figure 1-3 are some of the basic aerospace roles and missions that can be performed by the S^3 integrated weapons system. The missions that the S^3 can accomplish by itself are highlighted in gray boxes while other missions that are fulfilled as a result of the capabilities of the S^3 are indicated in plain boxes. A schematic of the fully mated S^3 concept can be seen in figure 1-4. The integrated weapons system that

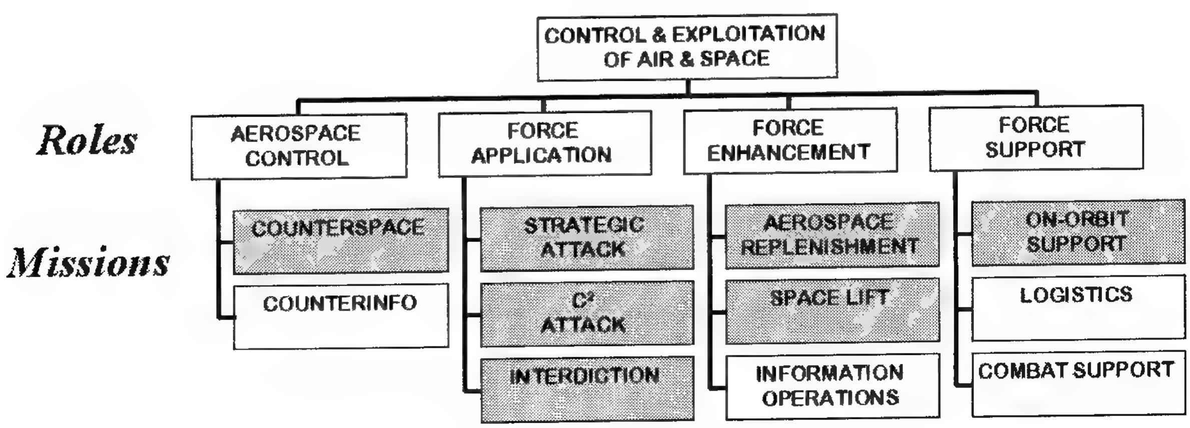

Figure 1-3. Aerospace Roles and Missions Fulfilled by S^3

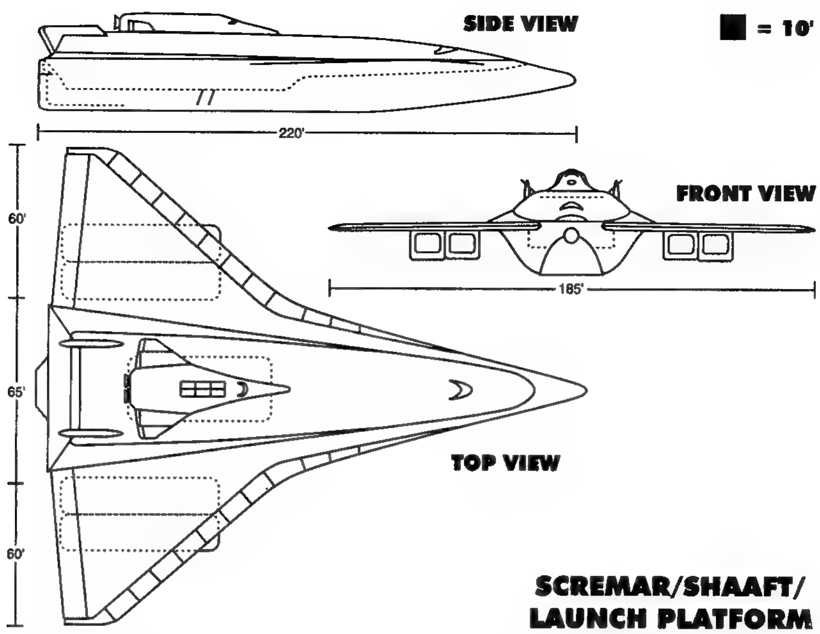

Figure 1-4. Schematic of Mated S^3 Platform (with SCREMAR)

has been described can perform counterspace tasks for aerospace control, tasks of strategic attack, of C^2 attack, and of interdiction for force application, aerospace replenishment and space lift tasks for force enhancement, and on-orbit support for force support. It is an integrated hypersonic weapons platform capable of accomplishing a diverse set of missions in a variety of situations.

Technology Considerations

Numerous technological challenges will have to be met before the proposed integrated, multistage weapons system can be built. However, none of these challenges presupposes that a breakthrough in technology is an enabling requirement. The zeroth-stage flying wing is a UAV with a maximum Mach number of 3.5. While that is slightly above the Mach number for the current high-speed civil transport design, it should not be difficult to solve the problems unique to this application, given that the proposed system would be fielded in the twenty-first century.

The design of the SHAAFT offers the greatest challenges because there exist no vehicles that have flown at sustained hypersonic speeds while powered by an airbreathing system. Furthermore, the aircraft should have global range with a payload of approximately 50,000 pounds. The use of a flying wing to transport the SHAAFT to the one-third point of its global range mission at a Mach number of 3.5 greatly simplifies the design of the SHAAFT. Considerable weight savings occur because the flying wing will carry the fuel required for takeoff, acceleration, and flight to the one-third point. The SHAAFT won't need heavy landing gear to support the takeoff weight. Furthermore, it does not need a zero-speed or a low-speed propulsion system. It appears that a dual-mode ramjet/scramjet combustor[8] could be used to accelerate the vehicle from Mach 3.5 to its cruise Mach number of eight or of 12 and to sustain flight in this speed range. The decision as to whether to limit the vehicle design to Mach eight flight or to extend its capabilities to Mach 12 flight is dominated by the propulsion system. Assuming reasonable

development of the technologies of hypersonic airbreathing propulsion systems and their fuels, it is assumed that Mach eight is the upper limit for the use of endothermic hydrocarbon fuels. One will need cryogenic fuels to extend the maximum cruise speed to Mach 12. Some of the pros and cons of this problem are presented in the "Critical Technology Requirements" chapter, tables 5-1 and 5-2. Based on the survivability and on the range of the SHAAFT as a weapons platform for delivering SHMACs and as the initial stages for the SCREMAR, Mach 12 flight would probably be preferred. Based on considerations relating to ground operations and support, especially if a recovery base is needed as an intermediate host, the endothermic fuels support a decision to limit the vehicle to a maximum Mach number of eight. In any case, a serious trade study (including the effect on the design of the TAV/orbiter and its payload) should be conducted at the outset of the SHAAFT program.

An aerothermodynamically efficient vehicle having a hypersonic lift-to-drag ratio of five, or better, will be a long, slender body with relatively small leading-edge radii (the nose radius, the cowl radius, and the wing leading-edge radius). Thus, the heating rates in these regions will be relatively high. Controlling the vehicle weight will have a high priority. Therefore, the development of high-strength, lightweight materials and the ability to efficiently use them for the load-carrying structure and for the thermal protection system are high-priority items. Researchers at the National Aeronautics and Space Administration's Ames Research Center are developing advanced Diboride Ceramic Matrix Composites (CMC), including Zirconium Diboride and hafnium Diboride materials which are reportedly able to withstand repeated exposure to temperatures of 3,660 degrees Fahrenheit and of 4,130 degrees Fahrenheit, respectively. Materials for thermal protection systems developed for shuttle derivatives, for the NASP, for the X-33, and for the X-34 should be reviewed for use in the proposed weapons system.

Major problems facing the aerothermodynamicist include the determination of boundary-layer transition criteria and the complex viscous/inviscid interaction associated with the multiple shock waves that occur, when the payloads (either the SHMACs or the SCREMAR) are released from the SHAAFT. The problem of developing boundary-layer transition criteria challenged the developers of the first reentry vehicles; it challenged the developers of the NASP; and it will challenge the developers of the SHAAFT. In the end, most likely, a criteria will be selected (with a degree of conservatism appropriate to the acceptable risk) and the design will proceed. The problem of shock/shock interactions associated with two objects flying in close proximity at hypersonic should be solvable. Some work has already been done on the staging of the Saenger.[9]

The decision to limit the SHMAC to a maximum flight Mach number of eight was straightforward. Since a variant of the SHMACs will be launched from conventional aircraft, such as the F-22 or the F-15E, simplicity of ground operations, of fuel handling, and of weapons loading at forward bases dictates against cryogenic fuels. By limiting the SHMAC to a maximum Mach number of eight, hydrocarbon fuels can be used. Use of hydrocarbon fuels instead of cryogenics greatly simplifies in-theater logistics, ground-support operations, and training requirements for base personnel. However, the SHMAC design must accommodate the transient loads associated with the short-duration overspeed when being launched from the SHAAFT.

Technology developments will be needed in the areas of guidance, navigation, and control (GN&C) and sensors for both the SHAAFT and SHMAC. Large changes in weight and in weight distribution will occur during the flight of the SHAAFT. Control of an aircraft flying at hypersonic speeds over great ranges requires advances in the state of the art. Collection and

interpretation of data (threats, targets, political considerations at the brink of war) and decisions as to how to react must be continuously incorporated into the mission plan.

The design of the TAV/orbiter, a.k.a. the SCREMAR, should make use of the large number of access-to-space programs continuing around the world, including international programs, such as, the Japanese HOPE, as well as US programs, such as the X-33, the X-34, and the XCRV (currently under development at NASA). Since the SCREMAR is all rocket powered and operates in a similar manner as the Space Shuttle once separated from the SHAAFT, it should use as much of the current technology incorporated by the Space Shuttle as possible.

The technology programs used to develop the SHAAFT can be transferred directly to the SHMAC and SCREMAR, and vice versa. This is another application of the term *integrated* weapons system. The development of the S^3 concept as a single weapons platform with several similar and fully compatible vehicles will be much easier on the technology demands as well the development costs than attempting to fulfill the same roles with different weapons systems.

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Chapter 2

Supersonic/Hypersonic Attack Aircraft (SHAAFT)

The SHAAFT (**S**upersonic/**H**ypersonic **A**ttack **A**ircra**FT**) is an airborne weapons system designed for operational use in the year 2025. It is capable of putting munitions on target, anywhere in the world, within four hours after takeoff. It is a direct result of the defined mission requirements of Global Reach/Global Power and specifically, Global Force Projection. The SHAAFT can fight and win two major regional conflicts simultaneously. It also complies with the current force drawdown in which the majority of all US military forces will be based in the continental United States (CONUS). Flight line operations would require cryogenic support for the fuel needs of SHAAFT. It cruises to and from the target at Mach 12 and at 100,000 feet. It is a completely reusable vehicle, like most USAF aircraft. The SHAAFT will deploy various weapons to destroy nearly any type of essential enemy target, dependent on real-time battlefield information or existing intelligence data to destroy targets. The SHAAFT will also serve as the base component to accomplishing in-theater dominance with the SHMAC and access to space with the SCREMAR.

The goal of the SHAAFT is to cause enough destruction and chaos in the first hours of a conflict such that the enemy realizes war is a futile choice. The enemy is then crippled and nearly defenseless against subsequent attacks from conventional forces in a protracted war. It would also serve as an extremely effective deterrent force, since the enemy would know that any military movement could be utterly upset if not completely destroyed within a matter of hours from its discovery. But unlike conventional aircraft, the hypersonic flight regime makes SHAAFT a difficult, and therefore highly survivable, target.

A hypothetical attack scheme consists of five SHAAFTs, dispensing nearly 50 hypersonic, precision strike, cruise missiles, for example, SHMACs. These would hit vital targets such as command, control, and communications facilities (C^3I network), power centers, transportation hubs, and potential space launch complexes. This attack alone would not cripple an advanced country's war machine, but it would severely disrupt their war-fighting operations to the point that they are no longer able to immediately continue any operations. Within hours of the initiation of hostilities, the enemy's infrastructure would be in shambles with their ground forces unable to communicate, maneuver, or fight a coordinated battle. The hostiles would then be unable to defend themselves against conventional military forces.

In the event that an enemy is able to perform some form of ASAT warfare, the SHAAFT would also serve as a staging vehicle for the SCREMAR reusable access to space vehicle. The SHAAFT/SCREMAR combination could be used to repair and replace damaged satellites. The system would be used in peacetime for routine replacement and replenishment of satellites, which would also produce operational experience that could be adapted to a critical wartime situation.

General Mission Requirements

CONUS Basing

The reasons for avoidance of overseas basing are extremely important. The SHAAFT, incorporating hypersonic technology, will be costly. Thus, few would ever be produced. This craft is essentially a "golden bullet" that will aid the United States (US) in deterring

conflicts, or if that fails, to win a war, hopefully in a short period of time.

Overseas basing provides the advantage of reduced range. But with shrinking defense budgets, such basing can no longer be relied upon. The security and stability of these foreign assets cannot be guaranteed in the year 2025. Basing the SHAAFT at large CONUS bases would enable a secure area in which to operate for years. Bases would be chosen such that infrastructure and geographic positioning could best support the hypersonic mission.

Cost-Saving

CONUS basing of the SHAAFT allows for security and stability in aircraft maintenance. But keeping the mission of global reach/ global power restricted to one aircraft saves a great deal of money. That is, the logistics usually required to maintain a fleet of attack aircraft are extensive and time-consuming, utilizing precious resources that could be saved.

The SHAAFT attempts to eliminate the swarms of tankers, airlifters, and support personnel that are normally required to sustain overseas operations. This aircraft takes off, deploys munitions, and returns, without refueling. Therefore, the SHAAFT saves money by reducing the logistics footprint required. It could save more money by stopping a war that would certainly cost billions. Had Desert Storm been prevented by a preemptive strike with well-placed munitions, the US could have saved many dollars in hardware and, more importantly, saved lives.

Hypersonic Requirement

The reasons that the SHAAFT must go hypersonic match the new face of warfare. It must make nearly instantaneous attacks while hiding under the cloak of survivability. If this attack aircraft travels at Mach 12 and 100,000 feet, it is improbable that 2025-era enemy technology would be able to overtake it. Considering the amount of time that it would take to detect, track, identify, and then launch an interceptor that must climb to 100,000 feet and then overtake the SHAAFT, the chances of losing the SHAAFT to an interceptor or surfaced launched missiles are next to impossible.

The SHAAFT would launch SHMAC missiles hundreds of miles from the hostile airspace of the enemy. Such a standoff attack would provide several layers of defense to the SHAAFT. First, the cruising velocity and altitude are unmatched by any current aircraft. Also, it is improbable that future adversaries would have the research and technology base to attain this envelope, although not impossible. Second, the aircraft never passes over a threat area. Enemy forces would undoubtedly see the SHAAFT coming, but a counterattack would have to occur far from their home base. Combined with the speed of the SHAAFT, the enemy force now has to fly a long way to intercept. Third, hypersonic cruise missiles like the SHMAC increases the synergy of the attack. These three layers of defense provide extensive protection against enemy forces.

The SHAAFT also serves as the staging vehicle for the SCREMAR. The achieve orbit, a transatmospheric vehicle (TAV), such as the SCREMAR, has to produce a large velocity change typically on the order of 25,000 feet per second for a LEO. The greater the velocity provided by the staging vehicle, the less the TAV/orbiter has to produce on its own, thus resulting in a smaller size or greater payload for the TAV. The overall effects of having the SHAAFT fly at different hypersonic speeds (i.e., Mach eight versus Mach 12, are covered in greater detail in chapter 5.

Range

Because of CONUS basing, the SHAAFT would require a large range. Because of the unusual flight regime and cryogenic fuels, tanker aircraft would be of little support (unless an entirely new tanker fleet were developed, which, under current budgetary constraints, is not foreseeable). Depending

on the enemy, the SHAAFT can attain a range of 14,000 nautical miles.

This large range requires a vehicle that is aerothermodynamically designed for a high lift-to-drag ratio. The range is directly related to the Mach number—the faster the flight velocity, the farther the range. This range also includes the turning radius. At Mach 12, the radius of a 2-g turn is 480 statute miles. The equivalent turn diameter equals about half the width of the US. Such a turn would take approximately 23 minutes, requiring long-term straining maneuvers of the pilot.

Payloads

Payload concerns include both the weight and volume. The SHAAFT is designed to carry a payload of 50,000 pounds. If the SHAAFT carries 10 cruise missiles at 4,000 pounds each, that leaves 10,000 pounds for pylons and supporting hardware on the aircraft. Furthermore, the SHAAFT is designed to carry an orbital vehicle. For instance, the SCREMAR, would be placed into low-earth orbit, requiring the volume of a light F-15.

SHAAFT Vehicle Concepts

The "Zero-Stage" Flying Wing

Because the SHAAFT will be taking off from conventional runways and operating across such a huge airspeed spectrum, the design team will have numerous challenges to overcome. How will an aircraft configured to cruise at Mach 12 take off from a runway and remain airborne at low speeds? These two speed regimes demand completely different wings, propulsion systems, and fuel systems. If the SHAAFT were to use turbofans for takeoff, then switch to ramjets, and then scramjets for hypersonic cruise, it would have to carry thousands of pounds of extra weight in the form of inert turbofan engines.

To overcome this problem, a two-stage vehicle is proposed. The "zero-stage" is an unmanned launch platform upon which the SHAAFT attack vehicle will achieve flow conditions conducive to ramjet operation (figure 2-1). The purpose of the launch platform is to lift the SHAAFT off of a conventional runway, then accelerate it to Mach 3.5 at 65,000 feet. At this point, the SHAAFT will be able to ignite its dual-mode ramjet/scramjet engines, separate from the launch platform, and accelerate up to Mach 12 and 100,000 feet. The launch platform will then return to base and accomplish a fully automated landing.

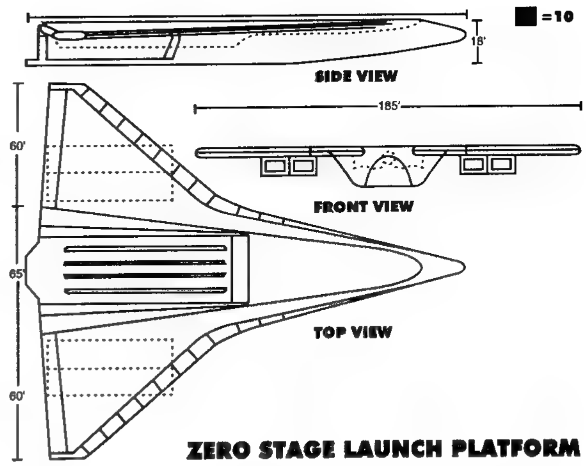

Figure 2-1. Zero-Stage Flying Wing

The concept of developing two independent aircraft seems extremely expensive in that two technologically advanced platforms must be produced. The SHAAFT will carry a substantial price tag, but the launch platform will be relatively inexpensive and will actually save large sums of money. A large majority of an airplane's cost comes from development and research. The technology to build the zero stage has already been developed (at least partially) in such aircraft as the high-speed civil transport (HSCT) and operational aircraft such as the Concorde. In addition, its mission is so narrow and specific that it will not require complex systems and components.

The zero stage will be required to accelerate down a long runway (no short field capability required), lift off without the use of complex lifting devices, accelerate straight ahead to Mach 3.5, release the SHAAFT, and then return to base. It must carry enough fuel for a radius of 5,000 miles at the higher Mach

number. It will not perform any demanding maneuvers or be subject to aeromechanically exhaustive flight regimes. Because of these limited demands, the launch platform will not incur large development or production costs. Furthermore, it greatly simplifies the design of the cruiser and dramatically reduces its size requirements.

Current design proposals consist of the following configuration, as studied by the National Aeronautics and Space Administration's (NASA) Boeing HSCT Study in 1989.[1] The proposed design is similar in platform to the HSCT, powered by six afterburning turbofans, each producing 50,000 pounds of thrust. A delta wing with a span of 160 feet and an area of 6,370 square feet would be able to take off with a gross weight of 2,000,000 pounds at 290 mph and a lift coefficient of 1.5.

It is essential that the SHAAFT be able to return to its home base or another SHAAFT-equipped recovery base. In order to do this, it will have to be able to land on a conventional runway. When it returns from a mission it will be much lighter than when it took off, having burned thousands of pounds of fuel. (The weight of the fuel is more than any other component on the aircraft, including structures and propulsion.) However, due to its aerodynamically configured shape, it will have to land extremely fast. It will need the assistance of a parachute braking system to slow down. Each SHAAFT would possess its own zero-stage vehicle, along with one extra for sustained operations through any contingency, in order to allow all five SHAAFTs to launch at once.

SHAAFT Design

Sizing and building the SHAAFT design will be the most difficult process. In this section, attempts to size the vehicle were made to fulfill mission requirements. The first step in deriving a platform involved the aerodynamic forces and how to use them to come up with a vehicle. The second step involved simple lift, drag, thrust, and weight trade studies to derive a generic design for the 14,000-mile journey to enemy territory and back. The third step verifies vehicle size using the Breguet range equation.

A unique phenomenon of high Mach number flight is the effect of shock interaction. The nose of the SHAAFT would create a conical shock around the body; such a shock results in significant pressure drag and must be overcome by propulsion systems. If the lower portion of the SHAAFT could keep the outer wing tips even slightly attached to the bottom portion of the conical shock, then the resulting total pressure on the bottom of the wing would be much higher than the top. This is the basic idea behind a waverider. The effect of the waverider can be modeled mathematically. If the bottom of the vehicle follows the same pattern as the stream lines of air, then it can be drawn as attached to the shock, as was done in a study by Dr Charles Cockrell of NASA Langley Research Center in 1994.[2] This can be seen in figure 2-2, where a Mach cone is generated mathematically in front of the waverider.

The waverider, which matches the flow (streamsurface), attaches to the shock and obtains a large lift-to-drag ratio (L/D), which enables much further range when compared to other hypersonic bodies. Although getting a shock wave to attach perfectly is impossible in reality, the initial shock angle can be made as oblique as possible, reducing pressure drag. When

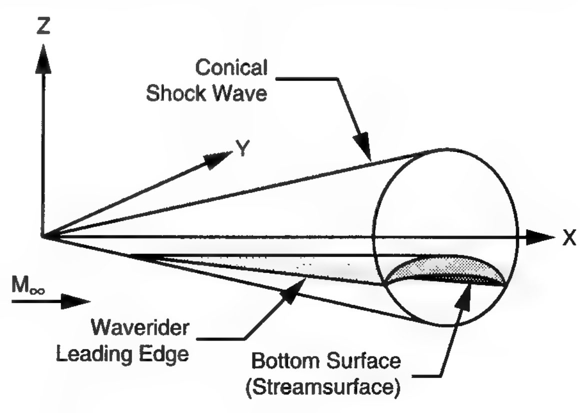

Figure 2-2. Conically Derived Waverider

combined with the high aerodynamic heating of hypersonic flight, the waverider background surfaces in the conceptual proposal for the SHAAFT: an aerothermodynamically configured vehicle.

Overcoming drag in excess of 358,000 pounds will be required by the power plant of the SHAAFT. A 10,000-mile flight at Mach 12 lasts approximately 74 minutes (this range subtracts the range of the zero stage). This figure includes time from zero-stage separation to engine shutdown and glide-in (in which no fuel is spent), therefore, extra fuel will be available for emergency contingents. The 74-minute flight will require the most amount of thrust for the least amount of fuel.

For Mach 12 flight, the large heating rates (which will be discussed later) cause dissociation of atomic oxygen. Typical, large-molecule hydrocarbon fuels—such as JP-4, JP-8, JP-12, gasoline, and other petroleum-based fuels—would suffer incomplete burning and poor efficiency under these conditions. The other fuel alternative is cryogenics such as liquid hydrogen, liquid methane, and others. Liquid hydrogen allows for the highest I_{SP}; its light molecular weight and high energy combustion rate make it ideal for the Mach 12 mission.

Several types of powerplants were considered, based upon the findings of the 1992 US Air Force Scientific Advisory Board. For this application, specific impulse was the paramount variable (fig. 2-3). Specific impulse is defined as:

$$I_{sp} = \frac{\text{Thrust}}{\text{Rate of Fuel Flow}} = \frac{T}{m}$$

Two alternatives exist for SHAAFT propulsion: rockets and dual-mode ramjet/scramjets. Rockets have excellent acceleration characteristics but poor cruising characteristics. Because rockets have such poor specific impulse, requiring their own oxidizers, ramjet/scramjets are the best alternative. Their air breathing technology, combined with hydrogen fuel, allows for the most "bang for your buck." As seen in figure 2-3, the I_{SP} of such a combination lies between

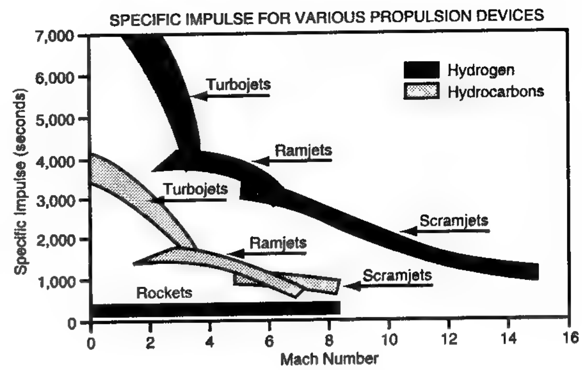

Figure 2-3. Specific Impulse Variation

1,400 seconds and 1,800 seconds. Since this aircraft would become operational around the year 2020, an I_{SP} of 1,700 seconds will be assumed for the design point.

The negative consequence to hydrogen fuel is the extremely large volume it occupies, which will cause the majority of sizing problems with the SHAAFT. One key to overcoming the density problem is using "slush" hydrogen. Dr F. S. Billig of Johns Hopkins University computed the density of different slush hydrogen,[3] and these can be viewed in table 1. For the technology level of 2020, a level of 50 percent solidification was

Table 1

Density Values of Slush Hydrogen (All Values at Triple Point)

Percent Solid by Weight	Density (lbm/ft)^3
10	4.81
20	4.87
30	4.99
40	5.05
50	5.11
60	5.16
70	5.22
80	5.28
90	5.34
100	5.40

assumed, resulting in a density of 5.11 lbm/ft^3. Using this denser hydrogen, the overall fuselage volume can be reduced, reducing drag.

To judge the size of the SHAAFT, a trade study was conducted to measure lift, drag, fuel requirements, and required fuel storage space. For the study, a lift coefficient of 0.125 and a drag coefficient of 0.025 were used to estimate appropriate aircraft length. These coefficients were chosen from experimental data performed by Dr T. Eggers and Dr R. Radespiel of the German Institute for Design Aerodynamics in 1993.[4] It was also matched with the mathematically derived "L/D Barrier" for conical flow derived waveriders, as seen in figure 2-4. At cruise speed, the maximum L/D is given by the expression:

$$\left(\frac{L}{D}\right)_{max} = \frac{4(M+3)}{M}$$

The $(L/D)_{max}$ value with this equation for Mach 12 is 5.0, which matched the values used in spreadsheet iterations.

The first step in the trade study was to pick an initial waverider size. With this, wing area was calculated using simple

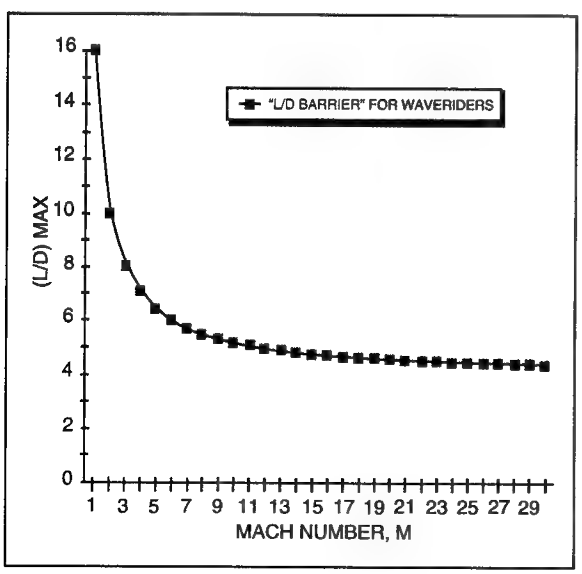

Figure 2-4. L/D Barrier for Waveriders

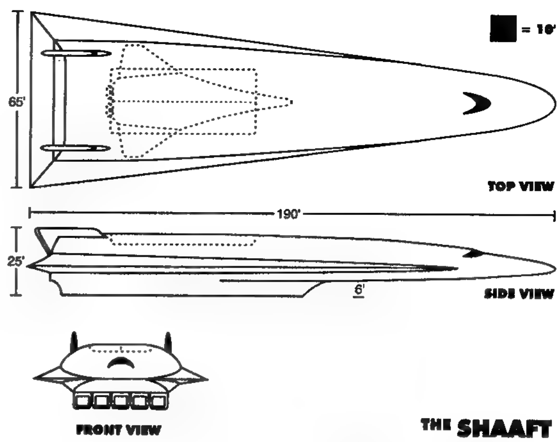

Figure 2-5. Supersonic/Hypersonic Attack Aircraft (SHAAFT)

triangular geometry. Figure 2-5 shows the basic geometry of the proposed SHAAFT. Knowing that lift is given by the equation:

$$L = C_L q\, S$$

lift coefficient was found. Using coefficient of lift and drag plots derived by Dr Cockrell during experimental testing, drag coefficient was found. With the familiar drag equation:

$$D = C_D q\, S$$

drag for the vehicle was found. With this value, thrust was known, since thrust equals drag in level, unaccelerated flight. With thrust, and the assumed I_{SP} of 1,700 seconds, the fuel flow was calculated. When multiplied by the total flight time, a fuel mass was obtained. This fuel mass was divided by the 50 percent slush hydrogen density to obtain a fuel volume.

Fuel volume was compared to available tank volume from initial waverider dimensions chosen. Using traditional aircraft design, the fuel tank accounted for 50 percent of total aircraft volume. With an actual fuel volume calculated, the aircraft size was changed to try to match available fuel volume with required fuel volume. Aircraft weight was calculated with this volume of fuel, and the assumption that five

pounds were required per square foot of wing area. This information was revealed in meetings with personnel of Wright Laboratory's Flight Dynamics Directorate, Wright-Patterson AFB, Ohio. This results in a SHAAFT body weight of 28,500 pounds, not including the 50,000 pound payload weight.

With the trade study, the fuel mass required met the fuel mass available at a waverider length of 190 feet. The tail end of the SHAAFT has a wingspan of approximately 60 feet. This design requires approximately 875,000 pounds of slush hydrogen to complete the 10,000 statute mile journey. The effects of the different iterations can be seen in figure 2-6. This particular iteration showed that the aircraft volume was too small, requiring further iterations.

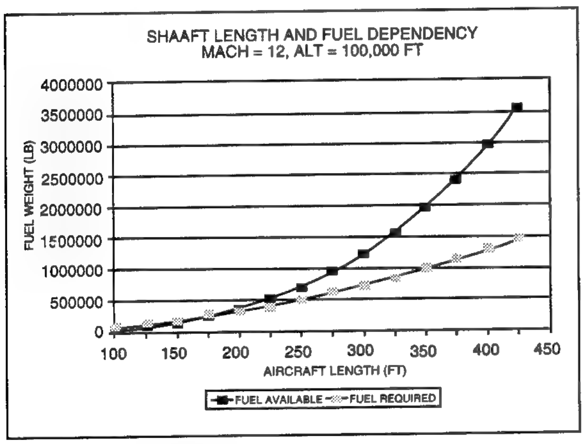

Figure 2-6. SHAAFT Sizing

The Breguet range equation can be used to verify the aircraft size. With the assumption of cruise flight only and at constant velocity, the equation is

$$\text{Range} = \left(\frac{V}{C_t}\right)\left(\frac{L}{D}\right)\ln\left(\frac{W_i}{W_o}\right)$$

where V is velocity, C_t is thrust specific fuel consumption, L/D is the $(L/D)_{max}$ for the SHAAFT at Mach 12, W_i is initial weight and W_o is final weight.

It is also important to note that C_t is related to the previously mentioned I_{SP}:

$$I_{sp} \approx \frac{1}{C_t}$$

Thus if I_{SP} is 1,700 seconds, C_t is 0.000588 pound/pound mass seconds. V is 11,891 feet/second, L/D is five, W_i is 954,000 pounds, and fuel mass required is 875,000 pounds, then W_o is approximately 78,500 pounds. Using the Breguet range equation, the mathematical range is over 25,000 miles, far exceeding the 14,000-mile requirement. However, the reason the mathematical range is nearly double what is needed is because the equation does not account for the excessive amount of fuel that is needed to takeoff and accelerate the SHAAFT to its cruise condition where it is most efficient. Approximately half the fuel will be spent taking off and accelerating the SHAAFT while also covering a large range. The extra calculated range is to ensure sufficient range throughout the entire flight. It also does not account for the large turning radius, given by the equation:

$$R = \frac{V^2}{g\sqrt{n^2 - 1}}$$

Here, R is turn radius, V is velocity, g is acceleration due to gravity, and n is the load factor of the turn. The SHAAFT would slow to Mach eight for turning and simultaneously launch SHMAC missiles. This gives a velocity of 11,890 feet per second. At a constant "2-g" turn, the radius is approximately 480 miles, assuming a 50,000 pound payload is still in the aircraft.

Flight Control Systems

Payloads will be placed on the back end of the SHAAFT, requiring room and center of gravity considerations. By the year 2020, the level of fly-by-wire technology should be very commonplace, and application of such technology to the waverider concept should be simple. The pilot would have a typical

control stick, interfaced with a black box computer. The pilot's inputs would be fed into two outboard split ailerons, giving both yaw and roll control, and into inboard elevons, giving both pitch and roll control. During cruise flight, such control inputs would be very minor, as surface deflections produce extreme moments at Mach 12.

Payloads would have to be located near the center of gravity of the SHAAFT. When these payloads are deployed, the shifting center of gravity could be disastrous if not properly accounted for in fuel ballast and in placement of loads along the fuselage. As 50,000 pounds of equipment depart the SHAAFT, the separation should occur smoothly and quickly to avoid dangerous situations.

Special Considerations

The unique mission and design of the SHAAFT will require facilities that are currently very rare or nonexistent. In addition to cryogenic storage and handling equipment, it will need an extensive facility to mate the SHAAFT with the launch platform. This would most likely be performed with a crane structure that would raise the SHAAFT into the air while the wing taxied into position beneath it (not unlike the space shuttle being mated to the Boeing 747). Automated facilities and technicians would then mate the two craft together.

Another consideration which can not be overlooked is the reality of an in-flight emergency developing and the SHAAFT being forced to land at a base which is not equipped to handle it. In this situation, some manner of getting the "Golden Bullet" back to the US would be imperative. This would be accomplished by dispatching a zero–stage wing to act as a ferry. The launch platform has extensive volume within its wings that is used up quickly during supersonic flight—but acting as a ferry, this range and endurance would increase substantially due to the low drag incurred by subsonic velocity. The alternative base would be equipped with a simple mating device, or if emergency demands, one could be airlifted to the foreign base. Once the two craft are mated, the launch platform will take off and return to CONUS. It is important to remember that the SHAAFT is essentially a flying gas tank and that most of its weight comes from fuel. It would obviously be drained of unnecessary fuel and payload for the trip back to the US to reduce the workload on the launch platform. The zero–stage launch platform would use conventional, hydrocarbon fuels for all points in its mission, landing at specific points around the globe to refuel.

Mission

Flight Profile

After being brought to Mach 3.5 by the zero-stage launch platform, the SHAAFT would release and pitch up, automatically initiating the start of ramjets. From there, it would accelerate and increase in altitude until it reaches the cruise phase.

The cruise phase, at Mach 12 and 100,000 feet, consists of the majority of the flight, including attack or SCREMAR transatmospheric vehicle deployment. The SHAAFT would continue at its cruise speed throughout the entire envelope, with the exception of takeoff, landing. This is due to safety considerations for the SHAAFT. If it entered or departed the target area at a much slower speed, to reduce negative aerothermodynamic effects, it would be vulnerable to more conventional types of attack. For instance, if an enemy country expected a SHAAFT attack, it could set up remote-based (possibly sea based, fleet launched) aircraft or SAM sites that do, and most likely will, have the capability in 2025 to destroy Mach 5+/– aircraft.

In the attack phase, the SHAAFT would launch missiles/munitions from a considerable distance away from the target. It would have to release its munitions early in the attack phase to allow the munitions to acquire and adjust its course at such high

speeds. Once the munitions were released, the SHAAFT would most likely make a constant 2-g turn and head back to the planned landing base. The precise routing would have to be precisely planned knowing that a 180 degree turn going Mach 12 may take place over several countries.

If the SHAAFT were launching an orbital vehicle such as the SCREMAR TAV, it would take off, adjust its course to get to the desired inclination, and release the TAV going Mach 12 at 100,000 feet. This gives the orbital vehicle an extreme advantage in potential and kinetic energy. An even greater advantage is that space access vehicles could be launched from any long runway in the world, rather than specific launch sites. This would be of an extreme advantage in wartime when it is possible and likely that our space centers will be a primary target.

Landing Phase

The landing phase would begin approximately 30 minutes prior to landing. While at cruise phase, the SHAAFT will shut down engines and decelerate to subsonic speeds to begin convectively cooling the skin surface. The glide aspects will be very similar to current space shuttle landings. It will continue gliding until touchdown, where the pilot can maintain control during the most critical phase of flight. The onboard computers would assist the pilot in setting up the airspeed and altitude adjustments to avoid pilot error.

The landing gear will be relatively small and only capable of operation during landing (due to the zero–stage launch platform). Since the aircraft weight is reduced dramatically during cruise flight (fuel is an enormous percentage of the total weight), and substantially during takeoff with the launch platform, the landing gear does not need to be extremely heavy, at least in comparison with takeoff requirements. This also assists in overall aircraft design by drastically reducing the weight fraction of the landing gear.

The flying wing zero stage was able to lift the SHAAFT off the ground at conventional airspeeds. But the SHAAFT, being an aerothermodynamically configured vehicle for Mach 12 cruise flight, would have much less lifting capability at traditional landing speeds. Therefore, it would have to land at high speeds, nearly 250–300 mph, which is similar to space shuttle landing speeds. In order to land this vehicle on large, but typical runways, a self-contained arresting system consisting of drag parachutes being deployed and extremely powerful brakes being applied upon landing would be incorporated into the design.

Payload Deployment

The inherent attack advantages of a hypersonic cruiser must not degrade its attack capability by deploying slow speed and ineffective munitions. Therefore, the focus of weaponry to be added to the SHAAFT should be newly designed and developed weapons that are capable of supersonic/ hypersonic speeds and contain extremely lethal yields. At first sight, the SHMAC missile is an excellent complement to the SHAAFT in that it flies at hypersonic speeds and is extremely lethal. It should also increase the range of the SHAAFT by approximately 1,000 nautical miles. This could allow the SHAAFT to either carry less fuel and more payload (weapons) or be more simply designed with less required weight (in fuel and range). It would also allow the SHAAFT to stay well out of enemy defense zones by using the less expensive, expendable SHMAC to fly into the threat zone. These two systems would be of excellent complement to each other.

Another nearly ideally complementary system to the SHAAFT is the space access mission complement that can be accomplished. With a typical TAV, the size of a light F-15, the SHAAFT could be a rapid, reusable, and extremely advantageous launch platform. It could carry TAV vehicles with the capability to launch them into orbit at any inclination and give them an initial,

"free," boost to 100,000 feet and Mach 12. This would be of extreme benefit to the simplification of the design of the still futuristic TAV concept.

The primary considerations are that weapons be developed with varied capabilities to be able to attack multiple types or targets depending what appears at the moment as the primary threats. In addition to the SHMAC, penetrating rods, flechettes, conventional bombs, self-guided antiarmor munitions, subnuclear munitions, and whatever is developed in future years are all possible payloads for the SHAAFT. They would all have to be developed much further, but there is a potential for some extremely powerful and lethal weapons arising from hypersonic speeds.

Overall, the SHAAFT has an extremely varied capability either to attack to or be used as a "mother vehicle" for various other missions. The "standard payload area" should be able to accept a myriad of different weapons and clusters of weapons. It should be capable of striking not only multiple targets in one sortie, but striking different target types with the varied types of munitions it can carry. For instance, it would be very feasible for the SHAAFT to fly abreast of a country the size of Iraq, drop a few SHMAC's at primary C^3 facilities, then drop precise "antiarmor" type munitions at key defensive sites. This capability would almost assuredly destroy the enemy's will and capability to wage war within a matter of several hours and a few sorties. High-value targets are key to success. With such a capability, it is assured that we could, on demand and nearly always, completely and definitively put a stop to the war before it begins.

Threats to the SHAAFT

Two possible threats that the SHAAFT could encounter are interceptors or laser weapons. The problems that an interceptor would face are enormous. It would have to detect, track, identify, launch, accelerate while climbing to 100,000 feet, and then overtake a target moving at 12 times the speed of sound. An interceptor that could do this would have to be traveling on the order of Mach 20. Even if the enemy did spend the money to develop this super surface-to-air missile (SAM), where would they put it? It does no good to place it near key targets because the SHAAFT is releasing its cruise missiles from 1,000 miles away! An enemy would have to create a ring of super SAMs thousands of miles long around its entire perimeter to keep the SHAAFT from entering. However, if the SHAAFT launches its payload from 1,000 miles out to sea, or over a neighboring country, little ground protection exists.

The other potential threat comes from lasers. The advantage that the laser has is that it can nearly instantaneously track and then fire at a moving target. It does not have to catch up to its target nor can it be outmaneuvered. But its disadvantage is its range and power supply. A laser that was powerful enough to reach both hundreds of miles downrange to the SHAAFT and 100,000 feet in altitude would require enormous energy stores.[5] A facility to supply this type of power could not be placed in a van and hidden on a mountaintop. It would be a sprawling, high-visibility complex that would be easily visible. Once again, if Special Forces units could not neutralize it before the attack occurs, the SHAAFT could attack the site from a thousand miles away or avoid it altogether.

Component Summary

The idea of the supersonic/hypersonic attack aircraft was derived by taking a look at what the US Air Force will need to accomplish in the year 2025. Gone are the massive enemies of east and west; gone also are the large budgets which could support their armies. Now the United States must deal with regional threats, in a timely manner, in a costly manner, and in a manner safe to the members of US armed forces. The SHAAFT is simply a tool to achieve these ends.

Hypersonics drives the missions of the SHAAFT. The infrastructure-intensive framework of supporting a fleet of turbine-driven attack aircraft reduces to a few supporting facilities in CONUS bases that support the SHAAFT. But the SHAAFT does not replace all existing and future Air Force inventory—it is a means to prevent the costly use of all other weapons. It saves money.

The SHAAFT has been designed to promote the proper usage of energy. By staging, it leaves bulky turbine engines on the ground as it completes the hypersonic attack role. By going hypersonic, the survivability of the SHAAFT increases tremendously. As of now, no known defensive weapons counter the SHAAFT threat; it simply flies too fast and too high. Upon completion of the mission, the aircraft would shut down engines and land on conventional runways, deploying drag parachutes to reduce the braking required. Such braking would occur with landing gear that has already been reduced greatly in weight due to the light airframe that would land back in the CONUS (the flying wing staging aircraft is equipped with bulky, expensive landing gear).

Technological improvements will be required to formalize this design. An operational ramjet/scramjet is key to designing such an aircraft. Aeroacoustic loads on the airframe cause many mechanical loading problems. Aerothermal heating requires the use of advanced heat dissipation materials. Command and control of the aircraft would require computational software and a hydraulics system that can perform under extreme circumstances. But many of the technologies for SHAAFT would be drawn from existing areas of research. The flying wing zero stage would utilize designs from the high-speed civil transport program. Waverider studies would finalize the design of the SHAAFT. Hypersonic research of ramjets would be used for power plant designs. Such measures should be easy in the information-rich age of 2025.

Imagine a single aircraft that could fly up the Mississippi River and simultaneously destroy key facilities at Falcon AFB, Colorado, Cape Canaveral, Florida, and Washington, D.C. A similar blow to some rogue nation would cause them to seriously question their current military and political endeavors. If you ignite conflict with the US, the motto is You'll Get The SHAAFT!

Notes

1. Boeing Commercial Airplanes, *High-Speed Civil Transport Study*, NASA Contractor Report 4234, under Contract NASI-18377, 1989.

2. Charles Edward Cockrell, Jr., *Vehicle Integration Effects on Hypersonic Waveriders*, George Washington University School of Engineering and Applied Science, 21 April 1994.

3. Frederick S. Billig, *Propulsion Systems from Takeoff to High-Speed Flight*, American Institute of Aeronautics and Astronautics, 1990.

4. T. Eggers and R. Radespiel, *Design of Waveriders*, DLR, Institute for Design Aerodynamics, 11 October 1993.

5. During the Strategic Defense Initiative development, several laser systems were proposed that would be powerful enough to fire into space. Remember that these were fired straight up through 50 miles of atmosphere to reflecting satellites. A laser attacking the SHAAFT would have to fire at a slant angle through a thousand miles of atmosphere, refracting the beam and posing much less of a threat.

Chapter 3

Standoff Hypersonic Missile with Attack Capability (SHMAC)

The SHMAC (**S**tandoff **H**ypersonic **M**issile with **A**ttack **C**apability) is proposed as a weapon system which has in-theater dominance capability. This weapon system strikes quickly, accurately, and can survive enemy air defenses. The SHMAC can be fired from future hypersonic aircraft such as the SHAAFT (supersonic/hypersonic attack aircraft), from a low-speed conventional aircraft like the F-15E or the future F-22, from standard ship-based vertical launch system (VLS) tubes, or from mobile or fixed ground launch sites. The propulsion system and warheads will be varied to accommodate the launch platform and the service employing the SHMAC, be it the Army, Navy, Air Force, or Marines. In order to best exploit the range and response time of hypersonic weapons, the SHMAC will be most effective when launched from a hypersonic weapon system, such as the SHAAFT. The SHMAC concept has evolved into an in-theater dominance hypersonic missile, whose design is based upon the need to strike quickly with a high probability of success. The SHMAC will be the primary weapon delivered from the SHAAFT. Its range allows the SHAAFT to safely deliver SHMACs outside the range of air defense systems.

The United States armed forces do not have the ability to strike enemy centers of gravity quickly, decisively, and with a high degree of safety. To destroy targets such as space launch facilities, power grids, communication facilities, and command centers, a rapidly deployable, highly survivable, extremely accurate weapon is needed. Hypersonics is the key to reaching these heavily defended targets in a timely manner and attacking them with a high probability of success. The range and response time inherent in a hypersonic weapon gives the United States armed forces the ability to destroy any ground target in any theater. This is an enormous advantage for US forces as it allows complete in-theater dominance. The SHMAC is a hypersonic weapon system capable of fulfilling this mission.

Several factors drive the design of the SHMAC. These include range, time to target, survivability, guidance requirements, payload requirements, launch platform size restrictions, heating rates, acceleration loads, and maintenance requirements. Initial designs include easy-loading modular payloads. The limitation for the payload is a maximum warhead of 500 to 1,000 pounds. This restriction is driven by the weight limit and size limit of the entire vehicle. Modularity offers flexibility of application of the SHMAC in a fluid war environment.

The missile body has a conventional cruise missile configuration adapted for hypersonic speeds. The propulsion concept is a combination of a rocket for the initial acceleration and a scramjet for sustained propulsion to the design speed of Mach eight. The rocket engine will not be necessary for the high-speed air-launched version (SHAAFT launched) because the missile will be deployed at or above cruise speed and altitude. The technology for the rocket/dump combustor-scramjet propulsion system has been studied in the ramjet form by engineers at the Flight Dynamics Laboratory at Wright Labs from 1977 to 1980.

The leading edges could be comprised of ablative materials or an ultrahigh temperature ceramic (UHTC) composed of a dibromide material like ZrB_2/SiC.[1] Ablators are an economical thermal protection system (TPS) because the SHMAC is a single use weapon. Ablators are much less expensive than more

exotic reusable materials. The shape of the missile will not change during flight when high temperature regions are protected with UHTC materials. This ensures that the flight characteristics of the missile will not change during the course of the flight. The ablative technology employed in the TPS is currently available, while UHTC materials are currently being developed by the Ames Research Center.[2]

The guidance technology takes into account the unique high-speed environment in which the missile will be operating. Possible technologies employed in the SHMAC guidance system include inertial navigation systems (INS) and global positioning system (GPS) usage for the cruise phase. Synthetic aperture radar (SAR) and infrared (IR) guidance is employed in the missile's terminal phase. The technology required to support the design of this missile should mature and become readily available within the next 10 years.

The SHMAC is the first step in developing a line of hypersonic vehicles to meet the needs of the Air Force well into the twenty-first century. These technologies will build upon each other, covering the complete spectrum of hypersonic speeds all the way to orbital velocities. The weapons systems range from in-theater dominance to global and space power projection. This hypersonics program will be an integrated effort (S^3) which allows one program to build upon previous research and development and the lessons learned in the other projects.

General Mission Requirements

Range and Time to Target

There are several minimum requirements that military planners have set for a hypersonic weapon system like the SHMAC. The ultimate constraint is for the missile to have a range of 1,000 nautical miles or more. It is desirable to be able to travel this distance in approximately 20 minutes although this is not as important as the range. Figure 3-1 shows the effective ranges of the high-speed air launched, low-speed air launched, and surface launched

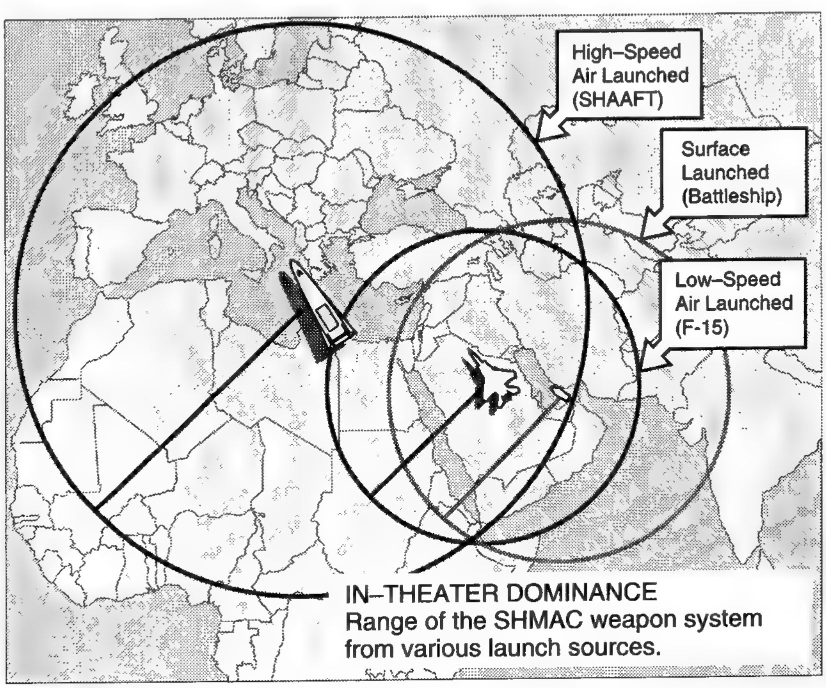

Figure 3-1. Effective Ranges of the SHMAC

SHMACs in the Middle Eastern and European theaters. The time-to-target requirement of 20 minutes is based upon the time from missile launch until the SHMAC reaches the intended target. This time requirement, as well as survivability considerations, drives the need for the missile to cruise at Mach eight. Technologically, Mach eight is an upper limit on the speed because of the desire to use endothermic hydrocarbons as a scramjet fuel, eliminating the need for cryogenics and the associated complexities.

Cost-Effective

With today's budget constraints it is nearly impossible to justify any acquisition program to Congress if the cost is too high. In order to keep costs low, existing technologies, modular designs, low-cost materials, and start-of-the-art or evolutionary design techniques will be employed. While hypersonics may be thought of as a revolutionary application, new designs can be developed on a technology base of more than 40 years of work. Furthermore, the design and development costs of the SHAAFT/SHMAC combination will be offset by the money this team saves in the long run.

Developing and employing the SHMAC will allow the US to maintain a strong military presence, while staying within the limits of our own borders and military budget constraints. The SHMAC has the ability to avoid a protracted war by reducing the enemies' will and ability to continue a war. This minimizes, or could eliminate, the costs associated with a major force deployment. This cost is not only measured in dollars but more importantly in human lives. If a conflict can not be avoided, the SHMAC has the ability to save lives, aircraft, and operational costs by striking heavily defended, hard to reach, key targets with accuracy and lethality. At first glance the price tag for this Platinum Bullet may seem high; but when all the opportunities and benefits are considered this is an economically feasible weapon system.

Operational Simplicity

The missile will be relatively inexpensive and operationally simple. This includes technology considerations such as thermal protection systems, propulsion and fuels, payloads, and guidance as well as base infrastructure such as missile maintenance and other support activities.

At a Mach number of eight and an altitude of 100,000 feet, the aerothermodynamic environment produces high surface temperatures, approximately 3,500°R at the stagnation points. This environment drives the design of the thermal protection, propulsion, and guidance and control systems. The TPS for the nose and leading edge will be comprised of either ablators or UHTC. Existing rocket technology will be utilized in combination with a scramjet. The weapons' bay will be designed to accommodate existing warheads and smart submunitions. Guidance and control will take advantage of GPS and SAR technology to acquire and destroy targets.

A goal throughout the entire design process has been to keep the missile's required support, maintenance, and other infrastructure very small, simple, and cheap. The missile requires only a small number of support personnel to maintain it. Since it is one use only, there is no need for through-flight maintenance. All munitions crews will be trained in proper methods to handle the SHMAC. Therefore the missile can be shipped or flown to the operational theater and be ready for deployment on any aircraft without requiring specifically trained personnel. Since it will be hard to know exactly what the targets will be in advance, the missile design also allows for easy transfer of existing munitions into the missile. Personnel trained to prepare the missile can configure the SHMAC for any mission on a moment's notice by interchanging the modular payloads.

SHMAC Vehicle Concepts

SHMAC Design

Three distinct versions of the SHMAC will be originally developed to allow for launch platform diversity. The versions are high-speed air launched, low-speed air launched, and surface launched. The high-speed air launched category includes all hypersonic delivery platforms. The SHAAFT will deliver SHMACs designed for high-speed launch. The low-speed air-launched category includes current and future transonic attack aircraft. Existing aircraft which could launch SHMACs include the F-15E, F-16, F-14, B-1, B-52, F-111, P-3, S-3, and the B-2. The surface-launched category includes both ship launched missiles from a standard Navy VLS tube, as well as ground launched missiles from a mobile or fixed launch platform.

A unique design feature of the SHMAC is a platypus nose. This provides two distinct advantages. First, a platypus nose has a lower heating rate than a conical nose. This is due to the ability of the cross section to better distribute the heating across the missile nose in two dimensions, rather than concentrating it at a single point. The heating rates will still be high at the stagnation point of the nose. The second advantage is the higher lift-to-drag ratio inherent in a platypus nose design.

The missile configurations for the high-speed air launched and the low-speed air launched are virtually identical. A potential conceptual design is shown in figure 3-2. Both have the same dimensions, the difference is the additional weight associated with a rocket in the low-speed air launched version. The missile's dimensions are 180 inches long, 54 inches wide, 23 inches high, and a nose radius of 1.5 inches. There is one slanted surface on the bottom of the missile which forms the compression ramp for the air entering the engine inlet. This also provides a component of lift to complement the wings. A

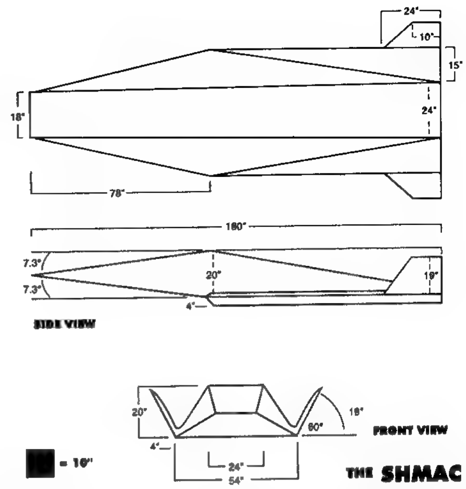

Figure 3-2. Standoff Hypersonic Missile with Attack Capability (SHMAC)

lift-to-drag ratio of 4.5 was determined for the SHMAC based upon calculations as well as values determined from other sources.[3]

In order for the system to be employed by the Navy through a VLS, it must be modified. The missile is longer and more slender in this configuration than the traditional SHMAC. This was driven by the need to retain volume for the rocket fuel while fitting within the slender confines of a VLS tube. The dimensions are 250 inches long, 16 inches high, and 22 inches wide. In addition, folding control fins are utilized to allow the missile to fit within a VLS tube. These will deploy after launch and provide the required control and stability for the missile.

The SHMAC exploits modular payload designs. This missile must be flexible in the types of targets it can hit. As a result, the SHMAC has the ability to change payload depending on the intended target. Payload variations range from high explosives to smart submunitions. Based on current missile designs, we plan to target the enemy with approximately 500 to 1,000 pounds of explosive material. The entire missile design is an iterative process that must balance propulsion, aerodynamics, payload, guidance and navigation, and many other considerations.

Propulsion

The first area of consideration is propulsion. For the low-speed air launched or surface launched SHMAC configuration, we recommend concentrating on developing an integral rocket/scramjet engine. This choice of engine is driven by the desire to accomplish the mission at a low cost without sacrificing effectiveness. This type of combined propulsion cycle provides high initial acceleration without multiple air-breathing propulsion concepts. The rocket will quickly accelerate the missile to high altitude and a Mach number where the scramjet takes over.

The driving force behind the entire design of this missile is the mission. However, as previously mentioned, further considerations must be made to account for the delivery platform. For example, if the SHAAFT will be the primary delivery system, the missile needs to be easily compatible with that aircraft. Further modifications need to be made if the SHMAC is to be used by today's fighter/bomber aircraft because of their unique limitations. Ship based SHMACs will be sized to fit into the Navy's VLS tubes. The largest modification for a land or sea fired SHMAC is the rocket engine. A rocket propulsion system is required to accelerate the SHMAC to cruising altitude and Mach number before the scramjet engine becomes effective. The rocket/dump combustor scramjet combination is shown in figure 3-3.

The SHMAC uses both a rocket and a scramjet to take advantage of the unique capabilities of each propulsion system. A rocket provides large initial acceleration at low Mach numbers. Rocket fuel is more dense than scramjet fuel due to the need to carry oxidizer within the fuel. Because of the low I_{SP}s of rockets, more fuel is required to produce the same amount of thrust. This means an "all rocket" concept is not desirable due to the large size and weight resulting from the rocket fuel.

On the other hand, a scramjet provides efficient high-speed cruise performance. This is due to its ability to gather oxygen from the atmosphere and its relatively high I_{SP} as compared to rockets. The I_{SP} for the rocket is due to the oxidizer contained within the solid propellant.[4] All of these attributes keep the size of a scramjet small. The drawback of the scramjet is its inability to function at low speeds. Therefore, the optimum propulsion concept is a rocket for low–speed acceleration and a scramjet for high–speed cruise.

A low-speed airbreathing concept without rocket acceleration would include a turbojet propulsion system. This results in the need for moving mechanical parts, increased expense and complexity, as well as large size and weight. A turbojet can not provide the quick boost of acceleration to scramjet operating speed and altitude that a rocket can. This high acceleration is desirable to reduce mission time and increase SHMAC

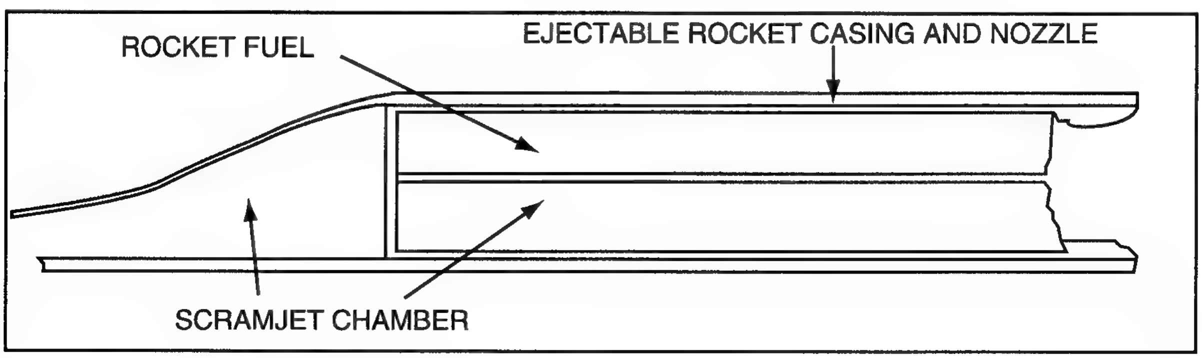

Figure 3-3. Rocket/Dump Combustor Scramjet

survivability. Since the SHMAC has a need for both quick response time and a long range, a combined propulsion system like the rocket and scramjet combination is a must.

The propulsion system which will be used in the SHMAC is a combined rocket and scramjet. This system incorporates an ejectable rocket case. The tolerances required for a scramjet to function in the Mach eight regime would be violated by using a scramjet chamber clogged with the remains of a burnt out solid rocket. The residue and spent fuel of the solid rocket will be removed from the scramjet chamber by ejecting the entire rocket casing after its burn is completed. The high heating rates along the combustor section of the rocket casing will be the most critical area driving the need for the engine material. Typical rocket fuels burn around 6,500°R.[5] A single rocket nozzle will be used. This provides simplicity, low weight, and low cost, though multiple nozzles would reduce the overall volume.

The rocket system, with its high initial acceleration, will be used to boost the missile up to a speed and altitude where the scramjet becomes efficient. Limited trade studies have shown an optimum altitude of 100,000 feet and Mach six for the transition from rocket propulsion to scramjet power. The scramjet system, with the advantage of highly efficient cruise capability, will keep the missile at its altitude and speed until reaching the descent point for the target.

Guidance

Another area considered is guidance. The missile will be programmable while in flight. This enables it to receive updated information permitting in-flight vectoring to a moving target. One means to accomplish this is an inertial guidance system with GPS redundancy which will be updated with the new coordinates as the target moves. A design challenge is ensuring that the guidance signals sent to the missile have enough power to penetrate the hot boundary layer and relay information to the guidance system of the missile. As the SHMAC nears the target area, it will employ self-guidance procedures.

One of these self-guidance procedures is synthetic aperture radar which will guide the SHMAC to a fixed target. This type of target may not have as distinctive a heat signature so a SAR system will have a much greater chance of success against this type of target. Today's SARs have resolutions of less than one meter at 70,000 feet, so the capability certainly exists to acquire and destroy a target using SAR.[6]

The most effective means to target a recently fired launcher is initial detection of the infrared signature of the launching missile coupled with radar tracking for pinpointing its location. The North American Aerospace Defense Command has the ability to use these two technologies to locate launch vehicles anywhere in the world. Sending the coordinates of the target to the SHMAC can be used to guide the missile to the target area. However, the final acquisition and tracking of the launcher must use a different form of terminal guidance such as IR or SAR because the launcher may have moved after launching.

Modular Weapons Bay

The SHMAC has so many different missions (flexibility is the key to airpower), that modular design to accommodate different weapons and guidance payloads is a must. This will simplify the tasks for maintenance crews on the flight line by allowing them to reconfigure the missile easily. In general, this missile will not be harder to maintain than another single use weapon like the Sparrow or Sidewinder. The rocket booster contains solid fuel and the scramjet uses an easily maintainable endothermic hydrocarbon fuel, JP-8 or some derivative. Fueling the missile before it is placed upon the aircraft will not require excessive support personnel or time.

Special Considerations

An important consideration in propulsion system design is the engine inlet. All three SHMAC versions are characterized by an underbody engine inlet that was shown in figure 3-2. A favorable forebody compression field is created by the interaction of the shock from the nose and the inlet lip. Other oblique shocks are formed along the inlet ramp to the combustion chamber which further slow the flow. The disadvantage of an underbody inlet is that the missile needs bank to turn in order to ensure good flow into the engine during flight maneuvers.[7] This increases the complexity of the flight control system.

The ideal intake scenario is one in which the flow transitions from laminar to turbulent upstream of the inlet. A laminar boundary layer is desired in front of the inlet, since it will keep the heating rates along the compression face of the missile lower than if this flow is turbulent. However, a mature turbulent boundary layer is required before the flow enters the inlet. This transition needs to occur soon enough so that the inlet shock has a turbulent boundary layer across it. The shock-boundary layer interaction works better with turbulent flow. Turbulent flow is also better suited for rapid mixing of fuel and air in the scramjet.[8] The burn phase must be completed extremely quickly for the scramjet to operate effectively. At high Mach numbers, the flameholders and fuel injectors must be highly advanced to successfully mix the fuel and airflow and fully combust it in the scramjet chamber for the most efficient burn.

One solution to the flameholder problem is to use highly reactive fuels (such as hydrocarbons with 20 percent ethyl decaborane).[9] Reactive fuels spontaneously combust when mixed with the airflow, eliminating the need for flameholders. This would enhance the performance of the engine by reducing the drag and flow problems caused by the flameholders. One problem with reactive fuels is safely storing and maintaining them as well as their high cost when compared to conventional fuels.

The scramjet will have an on-design point of Mach eight which is the desired cruising speed. To further reduce the cost, the inlet to the scramjet will be fixed geometry designed for Mach eight freestream velocity. Since the scramjet has no moving parts, the overall cost of manufacturing it will be fairly low, an important consideration in a single-use weapon. The cost of the scramjet is mostly driven by the materials contained in the scramjet/rocket engine. These materials will need to withstand the burning of the endothermic hydrocarbons and the oblique shocks formed on the inlet ramp.

The next area considered is the thermal protection system for the SHMAC. A great deal of thermal protection system research was conducted during the Apollo and Shuttle program. This research established many low cost thermal protection alternatives which are readily available for use on the SHMAC. The space shuttle program has also led to the development of new TPS. There has also been great progress in the study of ultrahigh temperature ceramics. Since the SHMAC is a single-use vehicle, the most cost-effective form of TPS seems to be ablators. However, significant research still needs to be conducted in this area as to what form of TPS is best for the SHMAC. Further considerations in this area are discussed in greater detail in chapter 5.

Mission

Flight Profiles

Spreadsheets were used to develop the high-speed and low-speed air launched and surface launched representative mission profiles. For each flight phase, values were calculated based on a simple free body diagram of the missile. The independent variables in this iteration were rocket boost end altitude, rocket boost downrange, descent downrange, acceleration cruise downrange, and unaccelerated cruise

downrange. The estimated rocket fuel and scramjet fuel values were adjusted to match the iterated values produced from the calculations. All of these variables were iterated and manipulated until the mission profile could be successfully met, and the overall vehicle weight did not exceed 4,000 pounds.

Several assumptions were made to produce these profiles. One assumption was that rockets have a thrust to weight ratio of 10. Another was that a scramjet at 100,000 feet has a thrust to weight ratio equal to 0.1.[10] A representative rocket fuel (polyvinyl chloride/ammonium perchlorate/aluminum) was used. This fuel has a density of 0.064 lb/in^3, burns at 6,150°F, and has an I_{SP} of 265 sec^{-1}. Scramjets operating at Mach numbers from six to eight have I_{SP}s between 900 and 1,200 sec^{-1} (see fig. 2-3). A representative scramjet I_{SP} of 1,100 sec^{-1} was used in the spreadsheets.

These iterations produced the following mission for the SHAAFT launched SHMAC shown in figure 3-4. The SHAAFT launches the missile at 100,000 feet at Mach eight. The scramjet ignites, and the missile cruises at Mach eight over the next 10 minutes. This cruise phase brings the missile 810 nautical miles downrange. Finally, the scramjet shuts off and the missile pitches over into the descent phase. This phase lasts for 11 minutes and allows a target that is an additional 620 nautical miles away to be destroyed. The entire mission gives the SHAAFT launched SHMAC a range of 1,440 nautical miles in a flight time of 21 minutes.

The second mission we considered was launching the SHMAC from a conventional fighter or bomber such as an F-15 or B-1. This low-speed air launched profile is shown in figure 3-5. The SHMAC will be launched from approximately 30,000 feet and Mach 0.8. The solid rocket booster accelerates the missile at an average flight path angle of 50° to 80,000 feet at Mach six. This results in an average acceleration rate of nine g's. The boost places the missile seven nautical miles downrange in 18 seconds. The cruise phase then accelerates the SHMAC to Mach eight, 100,000 feet and an additional 460 nautical miles downrange in a little over six minutes. The glide phase carries the missile another 630 miles downrange and slows it to Mach four. This gives this variant a total range of 1,100 nautical miles in 17 minutes.

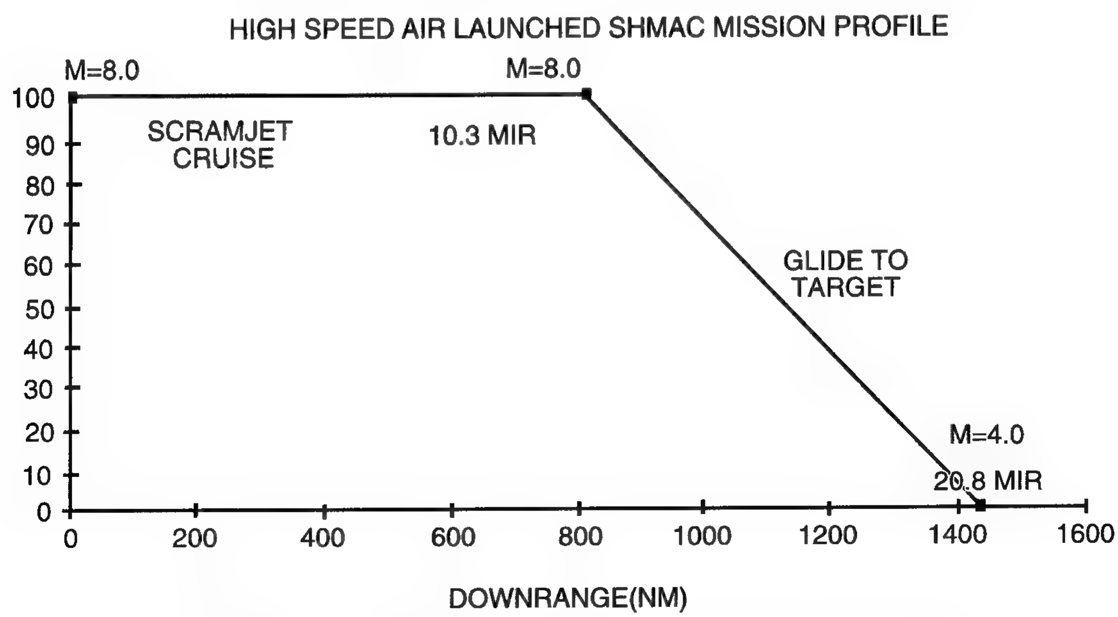

Figure 3-4. High Speed Air Launched SHMAC Mission Profile

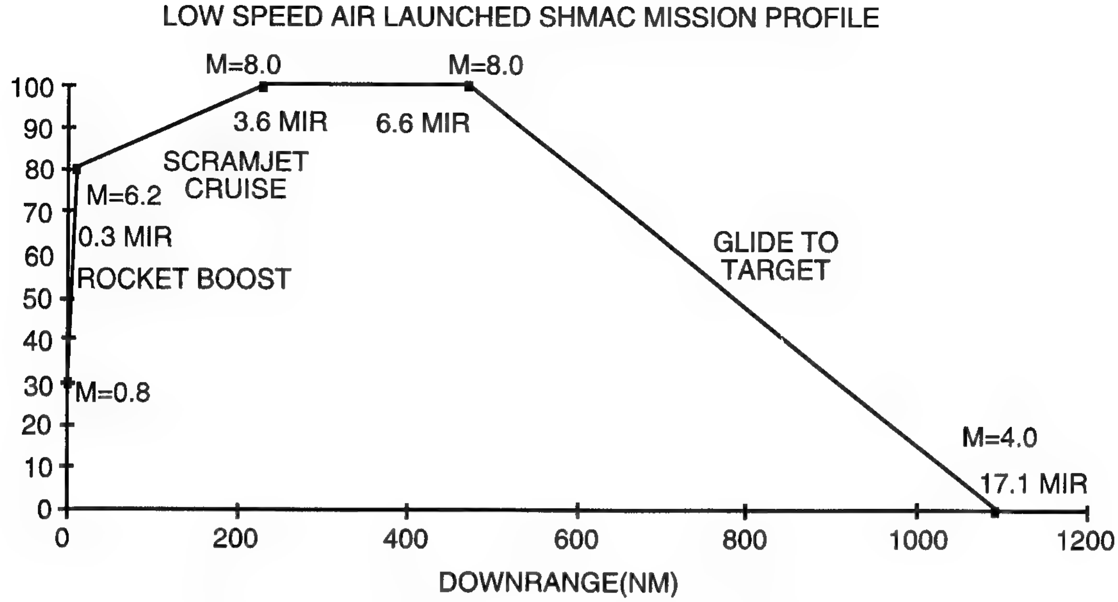

Figure 3-5. Low Speed Air Launched SHMAC Mission Profile

The third mission considered is for the surface launched version and is shown in figure 3-6. The SHMAC will be launched from an altitude of approximately zero feet and a Mach number of zero. The solid rocket booster accelerates the missile at an average flight path angle of 54° to 50,000 feet at Mach six. This results in an average acceleration rate of nine g's. The boost places the missile six nautical miles downrange in 20 seconds. The cruise phase then accelerates the SHMAC to Mach eight, 100,000 feet and an additional 410 nautical miles downrange in six minutes. The glide phase carries the missile another 630 miles downrange and slows it to Mach four. This gives this variant a total range of 1,040 nautical miles in 17 minutes.

Objective

The ability to attack key centers of gravity and strategic targets in a theater without prepositioned forces is beneficial for several reasons. This allows the United States to use its military instrument of national power immediately, at any location in the world. This ability can help avoid the development of a protracted conflict by immediately reducing the enemy's will and ability to fight a war. Of equal importance, the immense expense associated with maintaining an overseas presence during peacetime can be avoided by the development of a long-range quick-strike capability. The logistics footprint associated with a large deployment of US troops, like in Desert Storm, is a major expense and hardship on our nation. The SHAAFT/SHMAC combination avoids this footprint by providing the ability to strike anywhere in the world from a CONUS base.

The SHMAC gives the Air Force the essential capability to make a decisive strike in the first hours of a conflict. If a conflict arises, it takes a significant amount of time to mobilize a response force. The SHAAFT/SHMAC integrated weapon system gives the US the ability to strike enemy centers of gravity within hours.

Another advantage of the SHMAC is its ability to protect other war-fighting assets. The 1,000 nautical mile range of the SHMAC allows the SHAAFT to place weapons on target from a safe distance. The SHMAC is released from its host, be it a SHAAFT, F-15E, sea launcher, or ground

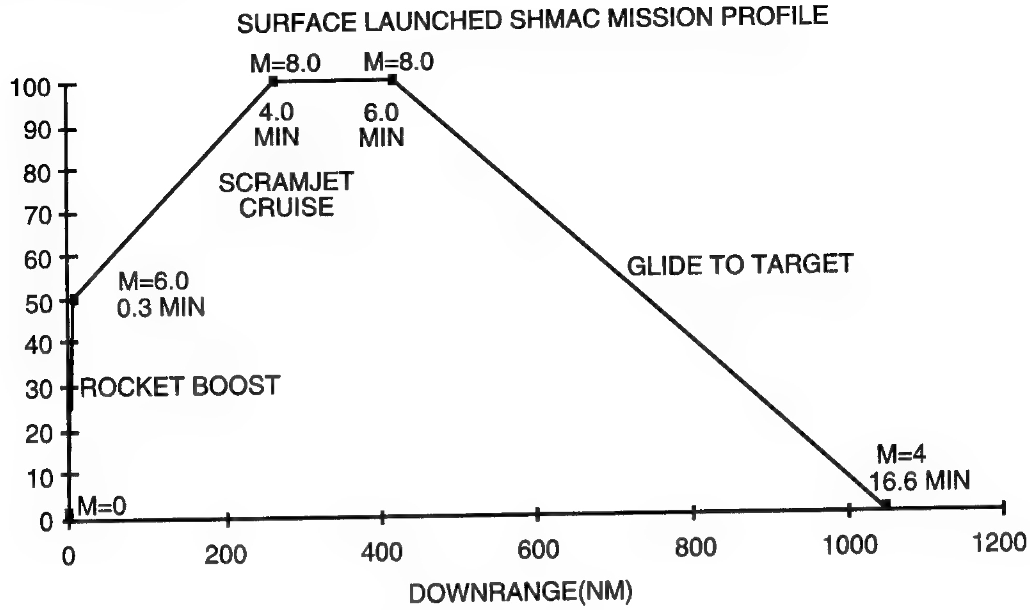

Figure 3-6. Surface Launched SHMAC Mission Profile

launcher from a distance safely outside of enemy air and ground defenses. The SHMAC can attack enemy centers of gravity such as command and control centers, access to space assets, and power and communication centers without putting more valuable assets, like aircraft, ships, and, most importantly, human lives into harm's way.

The speed of information gathering and distribution in warfare has matured at a phenomenal rate, but the military technology to deliver ordnance quickly enough to take advantage of this increased capability has not followed suit. The inability to attack detected targets of opportunity is a major shortcoming of our present force structure. These targets may include recently fired mobile ballistic missile launchers or military commanders whose whereabouts were recently discovered. This is where the speed and range of a hypersonic missile is a needed and crucial advantage. With SHMAC technology, the enemy will have no safe haven or freedom of movement. Anytime they are detected, they can be quickly attacked and destroyed.

There will be no escape from the oncoming SHMAC. The SHMAC will expand the Air Force's power-projection ability and increase our national security by enhancing the attack capability of all our armed forces. As mentioned earlier, the US military will now be able to stop the development of a protracted war without deploying any troops.

Possibly the greatest advantage of the SHMAC is its survivability. This weapon is highly survivable due to its mission profiles. The SHMAC will cruise at Mach eight and at an altitude of 100,000 feet. This flight regime is exceedingly difficult to reach with current air defense weapon systems. A surface-to-air missile system with 200 miles of coverage would have just over one minute to acquire and launch a missile at the SHMAC. This assumes the SHMAC is detected and classified as a threat at the limit of the missile's radar range. If they delay longer than this period, the missile will already be overhead and almost impossible to catch up to in flight. During the descent to the target, the missile never slows below Mach four and numerous submunitions can be deployed. Therefore,

there is very little chance that an enemy will be able to destroy it with a conventional surface-to-air missile in the terminal flight phase. Furthermore, the missile is not a dumb bomb but is capable of maneuvering, further increasing its survivability and success.

Possible threats to the SHMAC in the future are directed energy weapons such as lasers and microwaves. However, though these weapons may be developed, their complexity and high-power consumption will limit who is able to deploy them and how many are deployed. Only well-developed countries will be able to afford these weapons and only to protect key targets. This kind of threat is a definite possibility, but the standoff capability of the SHMAC ensures that the missiles will be targeted instead of manned aircraft, ships, or trucks.

Although the SHMAC has the potential to be used for many different types of missions, it was designed with a specific mission in mind. That mission is to strike a ground target 1,000 nm away in 20 minutes or less after release from a launch system. This mission was chosen to be the primary focus because it represents a current void in the US' ability to project military force. The ability to strike and destroy ground targets deep inside enemy territory is a mission that will continue to plague US forces in future conflicts unless this problem is solved now.

Future variants of the SHMAC may accomplish different types of missions using the same basic SHMAC technologies incorporated into the first version. These additional missions may include ballistic missile intercept, cruise missile intercept, air to air, surface to air, antiship, close air support, interdiction, and psychological operations. The speed and survivability of the SHMAC can enhance all of these missions. However, modifying the SHMAC to complete these missions will need to be accompanied by large advances in technology in other areas, especially guidance and control. This list represents the flexibility of a hypersonic missile, it is not an advertisement of the near-term capability of the SHMAC.

One of these missions, ballistic missile intercept, was a particularly plaguing problem for the US during Operation Desert Storm. The most effective way to destroy a ballistic missile is to reach it in its boost phase. Attempting to destroy the missile in the reentry phase when decoys, submunitions, and debris are present is extremely difficult. Hypersonic technology is required to reach a ballistic missile in the boost phase. The SHMAC could provide this capability.

Boost phase intercept capability will become more important in the future as more countries obtain the capability to employ weapons of mass destruction. We do not want to destroy a chemical or nuclear weapon over our own troops since the chemicals or fallout will then harm our own forces. Destroying a nuclear, biological, chemical weapon over our foe's territory is an extremely attractive option for a commander in the field.

When the technology required for a boost phase intercept is developed, this will still be a difficult mission for the SHMAC. One challenge in this mission is getting to the enemy missile while it is still in the boost phase. The SHMAC's speed and range is essential for completion of this mission during the enemy missile's vulnerable boost phase. The largest technological challenge is targeting another hypersonic missile in the air. Closure rates of well over 12,000 feet per second are probable when a SHMAC intercepts another missile. Not only must the SHMAC detect and track the missile, it needs to be able to physically strike the enemy missile to achieve a kinetic kill.

Component Summary

It is critical that funding be provided for the SHMAC immediately. With it the US will truly be able to dominate any theater during any future conflict. Also, the average cost of a fleet of SHMACs will still be considerably lower than the current cost required for the

Navy's Tomahawk land-attack missile to hit a target. In addition, it will be highly survivable, fast, and lethal. In short, **there will be no escaping the oncoming SHMAC.**

A hypersonic attack missile should be the first step towards developing an Air Force that can truly achieve Global Reach/Global Power through hypersonics. As explained before, the SHMAC falls into the first of three major categories of hypersonic vehicles: in-theater dominance, global reach/global power (SHAAFT), and access to space (SCREMAR). An in-theater dominance weapon like the SHMAC has the simplest mission and is closest to development today; using existing hypersonic vehicle and missile technologies. The SHMAC can become a stepping stone towards developing more complex vehicles and should later be integrated into other hypersonic platforms like the SHAAFT.

Notes

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Chapter 4

Space Control with a Reusable Military Aircraft (SCREMAR)

System Overview

The SCREMAR (**S**pace **C**ontrol with a **RE**usable **M**ilitary **A**i**R**craft) is a transatmospheric vehicle that can provide flexible, reliable, routine, and readily available access to space well into the future for a variety of applications. It is a multiple-stage-to-orbit (MSTO) vehicle designed for integrated use with the SHAAFT. It is 66 feet long with a gross takeoff weight of 50,000 pounds, roughly the size of an F-15, and fits piggyback on the SHAAFT. The hypersonic capabilities of the SHAAFT are used to take the SCREMAR to Mach 12 at 100,000 feet where the SCREMAR then separates. The SCREMAR then uses its two rocket engines to complete the remainder of the access-to-space mission in a similar fashion as the space shuttle, returning to a predetermined base for a horizontal landing on a conventional runway. Since SHAAFT produces a significant portion of the velocity change required to get the SCREMAR to orbit, the size of the SCREMAR can be greatly reduced while the payload increased.

The SCREMAR is a TAV/orbiter capable of carrying a 3,000-pound payload to a low-earth orbit. This payload will most likely be three 1,000-pound satellites, but there are also other options. The SCREMAR is not designed to replace the existing fleet of space launch vehicles. Rather, it is designed to fulfill a specific niche that current launch systems do not occupy. Specifically, the SCREMAR accomplishes the deployment and retrieval of satellites for a variety of scenarios (to include critical wartime replenishment), on-orbit support and repair of damaged satellites, and sophisticated ASAT warfare against vulnerable space assets of potential adversaries. Essentially, the SCREMAR can fulfill the essential mission requirements for spacelift, on-orbit support, and counterspace applications.

There are a variety of scenarios where an easily planned access-to-space mission is critical. The best means for accomplishing these missions is a reusable TAV/orbiter, for example, the SCREMAR. The most likely is a situation in which an adversary has managed to render a significant portion of a satellite constellation inoperable. In this situation, the SHAAFT/SCREMAR combination would be a means of quickly replenishing vital space capabilities. This would occur in two possible ways: the SCREMAR would take several new satellites to space to be deployed and replace damaged satellites or the SCREMAR could simply repair damaged satellites by docking with them in their orbit.

The role SCREMAR will play in helping the US maintain its space superiority status well into the future is crucial. In the past, and even present day, the US has enjoyed unopposed access to space, albeit at a very costly and time-consuming process. In the vastly changing political structures throughout the world, it is very likely potential adversaries will have the capabilities required to significantly hinder the missions we now accomplish from space through the use of satellites as well as our access-to-space capability. Due to its increasing importance, space is most likely to be the dominion of the modern battlefield.

The Need for Access to Space

The accelerated pace of the modern battlefield has dictated that the US become increasingly dependent upon their space assets. In fact, the success of the Army,

Navy, and Air Force throughout Desert Shield and Desert Storm was due in large part to the advantages provided by global positioning system, communication, and intelligence satellites. The war was won in the air and on the ground because there was no contest in space; the United States maintained control of the ultimate high ground throughout the entire conflict. In the future, space power and control over the ultimate high ground will be critical to winning battles on the sea, in the air, and on land. The SCREMAR can maintain this control.

With the increasing importance on space assets, the US cannot afford to neglect the necessity of space superiority. Space has become a vital means of communication, intelligence, and navigation for the Army, Navy, and Air Force in all military operations. Already in place are large and small satellites of varying types arranged in constellations to perform these and many other specific functions. Most nations of concern do not possess an adequate space infrastructure, but they do, however, possess the ability to level the playing field against the US through the use of nuclear weapons in space. For example, Russia and China, with their formidable space infrastructure, have the capability of posing a serious threat to US space assets. With the assets the US currently has in place and the vital role they fulfill in all military operations, America cannot lose a significant portion of this infrastructure and still function as a modern-day military power.

Nations without a strong access-to-space infrastructure (e.g., Iraq and North Korea) could still significantly hinder the US space capabilities at low costs and with little effort. Consider this: Iraq possesses an enormous Scud missile inventory and possibly the ability to procure nuclear warheads. This could be extremely dangerous to US interests abroad. Although the range of the Scud missile is very limited and nowhere close to being able to strike the US mainland, it is a ballistic missile with the capability of reaching the earth's upper atmosphere and lower regions of space if launched straight up. If fitted with a nuclear warhead, the electromagnetic pulse alone due to a nuclear detonation in the ionosphere could wipe out a significant portion of a satellite constellation's ability to operate effectively. Several detonations could make our satellite fleets inoperable.

Future concerns also include the possibility of a nation with notable space capabilities, such as Russia, performing sophisticated ASAT warfare. A resurgent ultranationalist Russia or a disgruntled China could either selectively engage and destroy our satellites as needed or use the previously mentioned method of random destruction depending on how many space assets they have in the area and if they can afford to lose them.

Satellites are extremely fragile spacecraft. This is due largely to the push for lower spacecraft weights (directly impacting lower launch costs) and the fact that no real threat exists in space to damage satellites other than the solar radiation damage (which we have made significant progress over the last few years in reducing) and the extremely unlikely and very rare event of the satellite being struck by a projectile of significant size, such as an asteroid or man-made object. The ability of a rogue nation with no legitimate space infrastructure being able to guide an object to impact a satellite in the vastness of space is an extremely difficult task.

However, with nuclear weapons, accuracy is not an issue. A nuclear detonation close to the earth's atmosphere in the lower regions of space would have enough energy alone to completely obliterate all satellites in the region overhead that are positioned in low-earth orbits. Although the exact effective region for such an explosion alone in space is unknown, it is estimated in the thousands of miles. Clearly accuracy is not a driving factor for an adversary wanting only to take out America's ability to look at

them for several hours; they could clear out the entire region above them while they launch a surprise attack on allied forces.

The damage to US satellites extends far beyond just what is done from the impact of the explosion. There is also an electromagnetic pulse that is dispensed by the explosion, extending for thousands of miles beyond the area affected from the detonation forces, which could incapacitate satellites' sensitive sensors and circuits, although the satellites' structures themselves would not be significantly damaged. This electromagnetic disturbance also tends to linger over an affected area for extended periods of time (e.g., several days) that make operations over the infected area extremely difficult until the disturbance had degenerated.

Regardless of the duration of the electromagnetic disturbance, there would be a significant US interest to replace those satellites in the constellation which have been destroyed and repair those which have been damaged. Replaced and repaired satellites should be ready to become fully operational as soon as conditions permit or in as little as a couple of days. Although current technology uses "hot spares" (satellites that are already in the constellation but not turned on) to cover for satellites that quit working for various reasons, these extra satellites would most likely also be damaged to some extent from the detonations. Using hot spare satellites that are in other orbital planes in order to reduce the impact of such an explosion is extremely difficult. Only if the satellite is in the same orbital plane does it have a chance of being effective in covering the area of responsibility for a destroyed or damaged satellite in an emergency situation. In the event that several nukes are set off at given intervals over an area, the effect of hot spares being able to restore previous capabilities is drastically reduced.

With flexible access to space through the use of a transatmospheric vehicle, for example, the SCREMAR, the military would be able to replenish destroyed satellites and repair damaged ones in a substantially reduced time frame relative to what is required by today's launch systems. This restoration time would be measured in terms of hours in getting a spacecraft that is on alert status into orbit with its payload of new satellites and/or replacement parts and getting the new/repaired satellites operational. A specially configured TAV could also perform various aspects of sophisticated ASAT warfare against enemy space assets. Also of importance would be the development of a technology that would readily allow access to space on a regular basis during all phases of conflict: before, during, and after the war. Having easily obtainable access to space on a regularly repeated basis would greatly increase the United States' chances of maintaining overall combat effectiveness through such a situation as previously described. Space control would become as regular a mission as air superiority. There is a definite need for the US to develop some form of countermeasure to the diverse space threats in anticipation of maintaining space control throughout the duration of any battle.

General Mission Requirements

The success of the access-to-space mission is dependent on several key requirements. Although not all of the requirements mentioned in this section are critical, they are necessary in terms of getting the flexibility, reliability, responsiveness, and low costs desired in an access-to-space TAV/orbiter. Some of the more critical requirements include (1) ability to get a 3,000-pound payload to a LEO, (2) 50,000-pound gross weight, (3) release point from first stage at Mach 12 at 100,000 feet, (4) launch-on-demand capability, (5) ease of mission planning, (6) small, flexible, highly trained ground crew, (7) build off of existing infrastructure as much as possible, (8) develop in conjunction with other hypersonic technologies, (9) rapid turnaround time, (10) horizontal takeoff and landing (HTOL), and (11) global reach from a suborbital

flight path. These requirements are directly related to increasing flexibility and cost-effectiveness. Other important requirements to be considered are manned and unmanned aircraft versions and modular cargo bay for ease of integration of various cargo and weapon systems.

Payload

The most critical requirement for a reusable military aircraft to fulfill the flexible access-to-space mission is the ability to take a sizable payload into a LEO. Having a military aircraft that is just designed to get to space without carrying any type of payload, as past programs have suggested, is virtually useless as a space control asset. The US' presence in space is based on the number of deployed and usable satellites.

Typical communication and intelligence satellites weigh in the neighborhood of 1,000 pounds or so and have dimensions roughly six feet x six feet x six feet when folded up. This is more or less the case for the newest constellation of satellites being deployed, the Iridium satellites, with expected reductions in size and weight in time with technology advances in materials and electronics. Having this capability would allow the SCREMAR to put approximately three satellites into a LEO (approximately 100 nm x 400 nm) in a single mission that can be planned and executed in a few days. Using today's technology, this would most likely take three separate missions with several weeks of planning in between each launch.

The benefits in terms of time and monetary costs can be seen from just this aspect while operational benefits extend even further. The SCREMAR could replenish an entire orbital plane of a satellite constellation with just three missions that could be accomplished in succession. The importance of the ability to plan and execute these missions in a short time as well as turn around the vehicle for subsequent missions quickly will be discussed in more detail later. Nevertheless, the importance of this capability can be seen in that satellites cannot be deployed (or repaired) if they (or the necessary tools) cannot be taken to orbit.

Sizing

The requirement for a gross takeoff weight around 50,000 pounds is driven by several factors. First and foremost is that this is the maximum payload of the SHAAFT. Also of importance is the fact that the lighter the overall weight, less fuel will have to be used to get the required change in velocity to get such a spacecraft into orbit. This places less demands on the need for significant improvements in both fuel and rocket propulsion technology. This relationship can be seen from the following orbital velocity equation:

$$\Delta V = gI_{sp}\ln\left(\frac{m_0}{m_0 - m_p}\right)$$

where g is the earth's gravitational acceleration, I_{SP} is the specific impulse of the fuel, m_0 is the initial mass, and m_p is the mass of the propellant. Thus, costs savings are realized both in terms of cost to build and cost to launch/operate when existing fuel and propulsion technologies can be taken advantage of.

The constraints placed upon a final stage TAV/orbiter from the first stage, for example the SHAAFT are critical. Having a TAV/orbiter much greater than 50,000 pounds causes a significant impact on the ability for the SHAAFT to accelerate the SCREMAR to Mach 12 at 100,000 feet. The rationale for needing to stage at Mach 12 at 100,000 feet is explained later; however, it is important to realize that the issues of size, weight of dry structure, weight of payload, weight of fuel, and staging are all interrelated and have significant impacts on each other. Previous studies, such as Blackhorse,[1] Beta,[2] and Saenger,[3] have concluded that a spacecraft roughly the size of an F-15 or F-16 would be the most beneficial configuration in terms of

technology required to produce such a vehicle.

Another important consideration is the fact that attempting to produce such an orbiter that carries an equivalent payload, 3,000 pounds, that is much lighter than 50,000 pounds requires a significant breakthrough in structure materials. As it stands now, the proposed SCREMAR's total weight is nearly 75 percent fuel and the other 25 percent encompassing both the payload and dry structural weight. As can already be seen, this is going to require improvements in structural technology; however, it will not require a significant breakthrough, only the natural progression of technology with time.

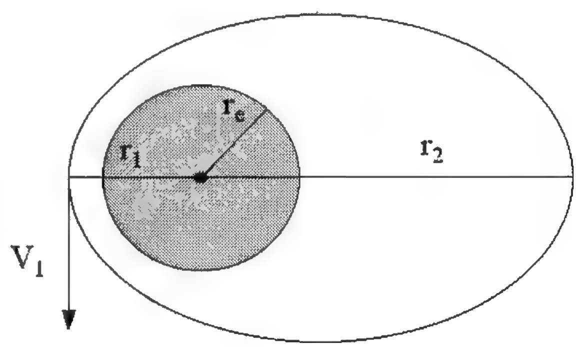
Staging

As alluded to earlier, there is also a critical need for staging at Mach 12 at 100,000 feet. Studies have shown that the altitude is not so much a factor as is the staging Mach number. In order to reach a LEO, the required velocity is around 26,000 feet/s (30,000 feet/s considering losses due to losses from pressure, drag, etc.). Since the desired orbit is at least 100 nm, the effects on required velocity change of staging at 50,000 feet versus 100,000 feet versus 150,000 feet are nearly negligible versus staging Mach number. The overriding factor is the change in velocity that the TAV/orbiter, SCREMAR, has to produce on its own. Staging at Mach 12 versus Mach eight means a starting velocity difference of approximately 12,000 feet/s versus 8,000 feet/s. This is a difference of having nearly 40 percent of the required orbital velocity supplied by the first stage versus 27 percent. Similarly, the staging height of 50,000 feet versus 150,000 feet is only between 10–25 percent of the total height above the earth needed, but the same velocity change has to be produced.

Staging at a lower altitude requires a larger vehicle since more fuel will be required to achieve the additional height as well as overcome the effects of air density. This places more demands on the structure all over, including weights and TPS. Staging at a higher altitude is limited to the capabilities of the first stage, for example, the SHAAFT, since it uses air-breathing engines. Either way, the same amount of total energy is required to put an object in orbit. The velocity of the TAV/orbiter that is required to get it to a specified orbit is given by:

$$V_1 = \sqrt{2\mu\left(\frac{r_2}{r_1(r_1 + r_2)}\right)}$$

where v_1 is the tangential velocity at the minimum radius, r_1 is the minimum radius, r_2 is the maximum radius, and μ is the earth's gravitational constant. The only biggest difference is how much of this velocity is supplied by the first stage, the SHAAFT, and how much will have to be supplied by the final TAV/orbiter stage. The diagram for describing this orbital equation around earth is given below (note: the figure is not drawn to scale):



Using the LEO previously described, r_1 would relate to the 100 nm part of the orbit and r_2 would relate to the 400 nm part of the orbit. However, this equation also takes into account the radius of earth, r_e, which is 3,443 nm (much greater than the 100 nm or 400 nm height above the earth's surface). For instance, $r_1 = r_e + 100$ nm and $r_2 = r_e + 400$ nm. Therefore, the real benefits in terms of the velocity change that would have to be produced by the TAV/orbiter considering staging at 150,000 feet versus

50,000 feet are less than 0.01 percent. Staging above 100,000 feet places other excessive demands on the SHAAFT since it is an air-breathing aircraft. Having a staging height somewhere below 100,000 feet means that more fuel will have to be burned to achieve the additional height, increasing operating costs. This would also mean that additional size would be needed to hold the additional fuel. In terms of benefits versus costs, 100,000 feet appears to be the optimum staging altitude. From this altitude, SCREMAR size increases significantly with a 50 percent decrease in staging height; but the size does not decrease significantly for a 50 percent increase in staging height.

The effects of staging velocity are even more critical. Using the two equations above and spreadsheets that varied the different parameters affecting the SCREMAR, relationships were determined between staging height, Mach number, payload weight, gross total weight, and fuel weight. Various fuels with different densities and I_{SP}s were used with staging heights between 50,000 feet and 150,000 feet and staging Mach numbers between eight and 12. With height, the only amount of additional fuel required is that to achieve an extra 50,000 feet or so of altitude. However, the study showed that much more additional fuel is required to produce the extra required velocity from Mach eight than from Mach 12 at every altitude than the amount of additional fuel required to produce the additional height from 50,000 feet to 150,000 feet at either Mach eight or Mach 12. Thus, a TAV staging at Mach 12 at 50,000 feet would be about half the size of a TAV staging at Mach eight at 150,000 feet. With the considerations mentioned before, the optimum staging conditions for the SCREMAR are Mach 12 at 100,000 feet.

Also, developing the technology for the first stage to have the capability to stage at Mach 12 will be less costly in the long run than trying to develop a TAV/orbiter of roughly the same size that overcomes greater velocity changes. The SCREMAR TAV/orbiter concept is already stretched in terms of existing technology for dry structural weight versus size. Having a staging point of Mach 12 at 100,000 feet greatly reduces the amount of fuel needed to achieve the required velocity change, and thus the overall size of the TAV/orbiter. Also, 100,000 feet is a reasonable altitude in which the SHAAFT can operate with sufficient air and without the excessive drag penalties. This topic is also discussed in more detail in chapter 5.

Operational Efficiency

The requirements for launch-on-demand capability, ease of mission planning, rapid turnaround time, and a small, flexible, highly trained ground crew go hand-in-hand. The requirement for launch-on-demand capability stems from the need for time-critical replenishment/repair of US satellites. Only by having the capability to replace damaged satellites in a short time can the US maintain the upperhand with space assets during a military operations. As previously mentioned, consider the case in which a majority of our space assets or a key satellite have been destroyed. Today's capabilities would require weeks to replace a single key asset, months or even years to replace a majority of a constellation. With the pace of the modern battlefield, the war could long be over before we could even get a single satellite on-line with today's launch systems. By having launch-on-demand capability, a mission to replace damaged or destroyed satellites could be under way within hours of the incapacitation of the satellites, thus getting the US back into the war with command, control, communications, and intelligence (C^3I) in a matter of days.

Of course, getting three satellites into orbit in a matter of hours is great, but really means nothing if another mission cannot be launched for several weeks. Thus, the need for launch-on-demand is required in conjunction with the need for ease of mission planning and rapid turnaround

time for vehicle missions. A given mission should be able to be identified and planned within a day's time. The proposed time frame for turnaround time, six to eight hours, is enough to allow for two missions to be completed in a single day, allowing also for a four to six hour mission time. A normal orbital plane of a constellation usually consists of five to 15 satellites, depending on the orbital height and number of satellites required in a field-of-view (FOV). Having six satellites placed in an orbital plane would be enough in most situations to provide substantial coverage over any given area.

It is also important to realize that these two requirements of launch-on-demand and rapid turnaround can only be met with a small, flexible, highly trained ground crew. The more people involved, the more time required for everyone to communicate and agree upon the status of the vehicle and increased chances of breakdowns in communication. Also, having a small, highly trained ground crew reduces the operating costs by not having to use as many resources to maintain operability. A small, flexible crew would also be much easier to transport in the event that the SCREMAR has to divert to a remote base. Most importantly, it implicitly requires that everything be done in a relatively simple manner. The less complexity, the cheaper the costs, the easier to operate and maintain, and the less chance there is for a major catastrophe.

Development

With the need for reducing the complexity of the overall system, there are a couple of complementary requirements: (1) develop critical technologies in conjunction with other hypersonic programs, for example, the SHAAFT and SHMAC, and (2) build off the existing infrastructure as much as possible. These requirements produce several key benefits to the program.

Savings in time and costs can also be realized by developing critical technologies, such as propulsion, fuels, TPS, and structural materials in conjunction with the other hypersonic programs of the SHAAFT and the SHMAC as well as extracting information and experience gained from vehicle and technology programs done and underway elsewhere. Since the technologies will be developed together, they will be cheaper in terms of the usefulness gained among the different systems (SCREMAR, SHAAFT, and SHMAC) rather than applying technology to only one. It will also make it easier to integrate the technologies among the three systems since they will be applicable to all systems. By building off of the existing infrastructure and developing hypersonic technologies together at one time, the SHAAFT/SCREMAR/SHMAC becomes a much lower-cost and less-complex integrated weapons system.

Infrastructure

Building off of the existing infrastructure means several things. Considerable monetary savings can be realized by not having to develop and build an entirely new and different access-to-space infrastructure. Existing infrastructures for both space and general aviation can be utilized and combined. Also, facilities for handling the support of the SHAAFT and SCREMAR combination will be available worldwide, for example, wherever the SCREMAR lands, providing greater flexibility to the SHAAFT/SCREMAR system. Only slight modifications to training and facilities would be required, reducing both costs and time to produce an operational infrastructure that is mission capable.

Building from the existing infrastructure has several advantages. First is the reduced costs associated with being able to redesign and utilize existing structures versus having to develop a completely new infrastructure. This is due primarily to the fact that almost everything needed to support operations is already in place and has already demonstrated the capability to support similar operations. Also, by combining assets from both the aero and space infrastructures, all

US Air Force aircraft operations could be conducted from one multifunctional infrastructure rather than three separate ones. This is consistent with the Air Force's movements towards composite wings. It also increases the flexibility of the SHAAFT/SCREMAR system by expanding the number of bases from which it can operate. This is an extremely important factor in the storage of fuels. If a majority of bases do not possess the ability to store the fuels required by both the SHAAFT and the SCREMAR, the base is essentially useless unless the fuels can be transported in by a special aircraft, such as a modified KC-10. However, if this is not possible, then the SCREMAR can be transported to wherever the SHAAFT is located via a Boeing 747, similar to the shuttle.

It is also necessary that the infrastructure be able to support both the SHAAFT/SCREMAR system. This is because the SHAAFT is required for SCREMAR operation. The SCREMAR is not designed to take off on its own. It must be loaded onto the SHAAFT in order to get off the ground. As designed, the SCREMAR is currently expected to fit on top of the SHAAFT. This could present some problems with bases having the capability to load the SCREMAR onto the SHAAFT in the situation where the SCREMAR must be diverted to a remote base. If a majority of bases do not have this capability, then they become useless. The means fitting the aircraft together, either to the SHAAFT or a 747, should either be transportable or extremely simple. The Beta concept of rolling the TAV/orbiter underneath the staging vehicle and then attaching it should be explored more.[4] In any case, the SHAAFT should be able to get to any location of the SCREMAR and at least be able to return it to a staging base, if not launch another mission from where it is.

As previously mentioned, requirements dictate that rapid turnaround is a capability that should definitely be sought after. The ability for rapid turnaround extends primarily from the ability to perform maintenance and other ground operations. Normal maintenance and ground operations, such as refueling and reloading, should be able to be accomplished in the desired time to meet the six to eight hour turnaround time requirement on the ground. Other maintenance and ground tasks, such as cleaning and damage repair, should be able to be accomplished within reasonable times. A good criteria would be approximately the same time it takes to accomplish these with today's fighter aircraft. Also of importance here are members of the ground crew. They play an important role in accomplishing all of the maintenance and ground tasks. They should be highly trained and specialized in accomplishing all of the necessary functions that occur on the ground.

Current launch systems are not standardized in their configurations. There is a definite need for standardizing launch vehicles and payload interfaces. Having payloads that are interchangeable among different vehicles increases the flexibility of both the payload and the launch system. This standardization also reduces the complexity involved with having to put similar payloads on different spacecraft or a variety of different payloads upon a single spacecraft, such as the SCREMAR. It could be done simply by using modular cargo bays that can be added and removed depending upon mission requirements and payload. Thus making it easier to reload cargo onto another spacecraft in the event that a mission is aborted prior to takeoff. The ability for cargo to be placed on different airframes allows for easier transportation of cargo to different bases. In a way, it also inherently implies that subsequent space transport systems will be developed. Having standardized payload interfaces also allows for the vehicle and payload to be prepared in parallel. Today's systems often require that the payload be prepared and loaded only after the vehicle is in place or vice-versa. Using modular cargo bays, the SCREMAR would be able to be prepared for launch and already loaded onto the SHAAFT

while the cargo is still being modified. The cargo could be loaded into the SCREMAR either before or after connection to the SHAAFT.

Special Considerations

Because of SCREMAR's integration with the SHAAFT, there are two other important requirements: (1) the capability for horizontal takeoff and landing and (2) the capability for global reach from a suborbital flight path. Like previous requirements, these two also go hand in hand. The ability for horizontal takeoff will be provided by the SHAAFT. Having this capability allows for the SHAAFT/SCREMAR system to operate from any base with a sufficient support structure and a conventional Class A runway. This would be extremely important in the event that the enemy has taken out our current space facilities at Vandenberg AFB, California, and Cape Canaveral AFS, Florida. In the event of war, these bases would become primary targets for a nation trying to hinder our space control capability. This ability also provides for greater flexibility in the planning, timing, and versatility of access-to-space missions.

Likewise, the capability for horizontal landing provides similar advantages along with others and is characteristic for both the SCREMAR and SHAAFT as individual aircraft. First is the reduced weight since the TAV/orbiter will be able to glide to a landing in a similar manner as the shuttle. The landing gear would only have to be designed to support the nearly empty weight of the TAV/orbiter since almost all of the fuel will be spent in achieving orbit. Landing vertically on rockets after reentering the earth's atmosphere not only presents a challenge but also requires that additional fuel be carried in order to provide significant thrust as the vehicle reaches the ground. Conversely, vertical landing would provide for the capability to land practically anywhere a concrete pad could be laid. Although already demonstrated through programs such as the DC-X, this technology need not be exploited since a little fuel will remain in the SCREMAR in order to ensure global reach from a suborbital flight path. Also, being able to land in the middle of nowhere does little good if the SCREMAR can not be efficiently transported back to a base where it can be mated with the SHAAFT and its zero stage. Nevertheless, the capabilities of global reach from a suborbital flight path would allow the SCREMAR to reach and land on any conventional runway in the world. Which is very essential if our current facilities are destroyed, especially if they are destroyed while the SCREMAR is accomplishing a mission.

The requirements mentioned throughout this section seem to be the most critical requirements driving the design of the SCREMAR TAV/orbiter concept; however, they are not the only factors to be considered. If the access-to-space mission is to truly ever become cheap, flexible, and reliable, there are millions of other considerations that need to be taken into account. A couple of the more important of these considerations seem to stand out. First is the potential to develop both piloted and unpiloted versions of the SCREMAR. The first step lends itself to the piloted version since real-time control and on-hands experience will be necessary in accomplishing the prescribed missions. However, with increases in technology, unpiloted versions will allow for the accomplishment of almost all of the prescribed missions (with the possible exception of only on-orbit support) while providing less risk of human casualties. Having less manpower to operate would also be a substantial benefit since the entire mission could be controlled by one person on the ground.

As alluded to earlier, another important consideration is a modular cargo bay with standardized cargo and weapon modules. This speeds up the turnaround time significantly since subsequent missions can already be preplanned and prepackaged before the TAV/orbiter even returns to the ground. It also reduces the costs of having to fit individual payloads to individual

spacecraft cargo bays. A standardized system could be incorporated that could be applied to future spacecraft, reducing the need to continually redesign cargo.

The requirements, as defined throughout this section, play a critical role in determining the final design of the SCREMAR TAV/orbiter concept. Obviously, these are not the only factors involved in developing access-to-space technology, nor are they absolute. Although there are many factors to be considered, these consistently appear throughout various studies to be the most critical in developing ready, reliable, flexible access to space. Concentrating on these requirements yields the greatest possibility of developing an access-to-space vehicle that successfully accomplishes all of the missions previously presented in this study.

Missions

With the increasing importance being placed on space assets such as communication, intelligence, and GPS satellites, the US can not afford to overlook the drastic impact of having a significant portion of the existing satellite fleet wiped out. It takes dozens of satellites in a constellation just to make the constellation operational enough for practical applications. With today's launch capabilities, it normally takes months, or even years, to insert a satellite constellation into orbit. This is due to the inefficiencies of only being able to take up one or two satellites at a time with launch intervals that take months to be planned and executed.

With the future possibilities of threats that face space assets, the US must have a viable means of maintaining control of space. As with maintaining control over the air, there must be a space infrastructure designed to provide Force Enhancement, Force Support, and Space Control. The most likely solution to accomplishing these missions with a single system is space control with a reusable military aircraft. A TAV/orbiter (fig. 4-1) roughly the size of an F-15 and capable of carrying a 3,000-pound payload to LEOs could fill the major facets of these missions by accomplishing ready, reliable spacelift and on-orbit support while also providing a platform for counterspace operations. In fulfilling these multiple roles, the advantages of flexible access to space with a single platform can be realized.

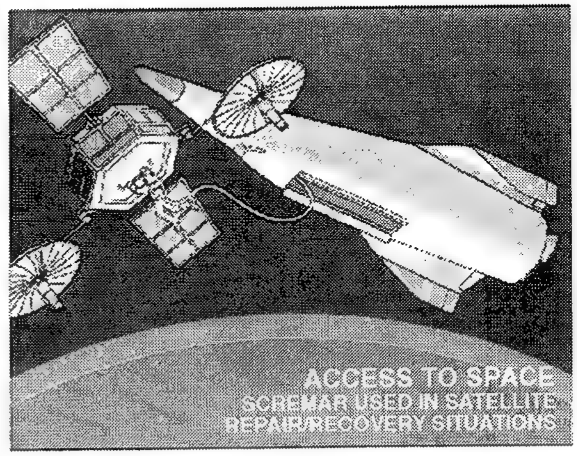


Figure 4-1. SCREMAR Performing Various On-Orbit Operations

The three primary missions to be accomplished by the SCREMAR TAV/orbiter are (1) deployment/retrieval of satellites, (2) repair of damaged satellites on-orbit, and (3) antisatellite warfare against enemy space assets. These missions (fig. 1-3) help achieve the broader concepts of Force Enhancement with spacelift and replenishment of space assets, Force Support by providing on-orbit support, and Aerospace Control through counterspace and counterinformation tactics achieved with ASAT. However, with the capabilities of a small TAV/orbiter, other possible missions still exist. SCREMAR could also be used as weapons platform for launching key strikes from above (strategic attack) as well as reconnaissance platform to gain and disseminate tactical information and intelligence in real time (information operations and combat support). These missions could be accomplished by manned or unmanned versions of the SCREMAR.

Deployment/Retrieval of Satellites

The current successes enjoyed by US space operations are due primarily to the large,

unopposed fleet of satellite constellations which has taken years to acquire. With an enemy capable of performing any of the various kinds of ASAT, these years and billions of dollars could become vain as the US would be unable to operate on the modern military battlefield. Having routine, easily accomplished access to space allows the effects of such a blow to be significantly reduced. This is best accomplished by the capability of ready, reliable deployment of satellites provided by a small TAV/orbiter. In a situation where the enemy has detonated a nuclear weapon, or a series of nuclear weapons, near satellite orbits, wiping out a majority of a constellation, the SCREMAR could be used to replenish destroyed satellites.

With a rapid turnaround mission time, the SCREMAR could deploy as many as six satellites within a single day. Time to get a complete satellite constellation on-line and operational could be reduced to just a few days. This limits the enemy's ability to downgrade our C^3I operations for any significant period of time. Satellite replenishment could be used in any situation in which more satellites are desired, including the cases where an enemy has selectively destroyed several key satellites and just adding new constellations for various reasons. The TAV/orbiter could also be used to retrieve severely damaged satellites and return them to earth for repairs. Although the need for this mission is clear during war, it could also be accomplished during peacetime to aid in the normal deployment of satellites on a regular basis, also providing operational experience to the crews of the SHAAFT/SCREMAR platform so that they have the knowledge and understanding to accomplish the same missions during the accelerated pace of war.

Repair of Damaged Satellites

In the situations described previously, not all satellites will be destroyed. In some cases, it might be more cost and time efficient to have many of the damaged satellites repaired while in orbit. This is especially true if all of the satellites are in the same orbital plane. The SCREMAR TAV/orbiter could accomplish this by simply slowing down or speeding up within the orbital plane to dock with individual satellites and repair them real time. This significantly reduces the costs of an operation by not having to take as much of a payload into orbit (only the necessary tools and replacement parts) as well as the costs of not having to actually build replacement satellites. Time would be reduced in that the in-orbit satellites would not have to be positioned nor configured. As soon as they are repaired, they would be on-line and ready to go.

This mission could also be accomplished in conjunction with the deployment/retrieval of satellites for maximum effectiveness, for example, the SCREMAR would reach orbit with replacement satellites and deploy them, repair the slightly damaged satellites, and retrieve the severely damaged satellites, all in one mission. As previously mentioned, the missions of spacelift and on-orbit support could also be performed during peacetime as a means of maintaining a viable satellite fleet as well as providing practice for routine access to space during wartime situations. This would be an essential portion of the training the crews receive.

Antisatellite Warfare

Another integral form in maintaining space control is space superiority. In a wartime situation, it is very plausible that our enemy will also have significant space assets. SCREMAR could be used to perform sophisticated ASAT to take out the enemy's "eyes" and "ears." Just as the destruction of our satellites could significantly hinder our C^3I capabilities, so could the destruction of the enemy's satellites hinder theirs. Having the ability to gain an intelligence advantage over the enemy and to be able to communicate when they cannot provides a significant advantage, especially in the fast pace of the

modern battlefield, as demonstrated in Desert Shield and Desert Storm.

This could be accomplished by fitting the SCREMAR TAV/orbiter with a weapons system capable of destroying satellites at varied ranges, perhaps a laser or other beam weapon. Also, the SCREMAR TAV/orbiter could simply "capture" the enemy's satellite, take it out of orbit, and bring it back to earth. The satellite could be dismantled and probed for valuable information with regards to the enemy. Another concept is to have the SCREMAR dock with the enemy satellite, similar to repairing operations (fig. 4-1), and "fix" the satellite so that it sends falsified information controlled by the US as a means of deceiving the enemy. This mission achieves several principles of war, including taking out the enemy's ability to see and communicate along with surprise by deception.

Additional Possibilities

Although these missions alone are enough to provide the US with the ability to control and exploit space, the SCREMAR is not limited to just these. Once the technology for a TAV/orbiter is developed, variations of the SCREMAR could be developed to serve as a suborbital or space-based weapons platform (depending on the various treaty requirements) for attacking the enemy from overhead as part of a strategic attack or as a reconnaissance platform for gaining wartime intelligence in real time. The SCREMAR could serve as the ultimate standoff weapon by being able to attack well out of range of any enemy fighter or missile.

Possible weapon configurations include an extremely powerful laser for attacking pinpoint strategic locations and the capability to release either conventional or nuclear "brilliant" munitions from the cargo bay and guide them to their targets from a suborbital flight path. As a reconnaissance spacecraft, the SCREMAR could be used to direct a battle in real time by gaining valuable intelligence information from above and sending it to particular on-field commanders. The TAV/orbiter could also be used to gain information in a gap that working satellites do not cover.

Operations

Having a well-developed infrastructure does not mean just being able to provide maintenance to the SCREMAR while it is on the ground. The infrastructure must also have the necessary systems to allow the SHAAFT/SCREMAR to function operationally. This is in reference primarily to the control centers that communicate with, exchange information with, and direct operations of the SCREMAR. It is the operations of the SCREMAR that accomplish the missions, not the ground operations. Operationally, there are four phases of a mission that must be considered: (1) preflight, (2) takeoff/separation, (3) space operations, and (4) reentry/landing. Each is unique and presents its own challenges to the SCREMAR.

Preflight. The preflight phase includes all of the ground operations: mission planning, refueling, loading cargo, loading onto the SHAAFT, maintenance, etc. The importance of many of the factors to be considered during the preflight phase have already been addressed. The main focus in this phase is on the ability to have reliable and quick ground operations that allow for the SCREMAR to be launched on demand and accomplish successive missions rapidly. Of great importance is the ability to be able to reload the SCREMAR with cargo and onto the SHAAFT for a turnaround mission. It is in the other three phases where the SCREMAR as an operational vehicle will earn its money.

Takeoff/Separation. The takeoff/separation phase begins once the SHAAFT has started its takeoff roll and ends once the SCREMAR has successfully separated from the SHAAFT and is climbing to space under its own power. The SCREMAR will be loaded in a piggyback fashion aboard the SHAAFT. The SHAAFT will already be placed on its zero-stage flying wing. Essentially, the SCREMAR will take off by means of the SHAAFT's and zero-stage's engines as a

multiple-stage-to-orbit (MSTO) vehicle. Upon departure, the SHAAFT will separate from its zero-stage around Mach 3.5 at 60,000 feet, as previously described in chapter 2. The SHAAFT will then continue to accelerate and climb to its maximum velocity of Mach 12 at 100,000 feet. Here, a pop-up maneuver will be performed in which the SCREMAR will detach from the SHAAFT. Once free and clear from the SHAAFT's wake, the SCREMAR will ignite its rocket engines and accelerate to orbit.

There are a couple of very important factors that need to be examined during this phase. First is the shock/shock interactions that would occur during separation and the impact they would have on both the SHAAFT and the SCREMAR. If they cause significant problems, then ways to reduce the problems need to be sought, such as releasing or ejecting the SCREMAR directly backwards. Another consideration is how the maneuver should be performed to release the SCREMAR or if any maneuver needs to be performed at all. This is the most critical phase of the entire mission. More things could go awry here than at any other time, with a likely exception being the landing phase. Nevertheless, separations at these high speeds have never been demonstrated before and must be studied extensively in order to quantify the effects and reduce the chance for mishap. Other possibilities for failure during this phase, such as rocket engines not igniting, the SCREMAR not separating, and so forth. need to be carefully examined to ensure successful completion of the stage.

Space Operations and Reentry/Landing. The next phase is where the mission accomplishment occurs, space operations. This phase, although complex, has already been demonstrated in some respects by the shuttle and other space vehicles. Similarly, so has the reentry/landing phase. Important items to be considered in these two phases have already had extensive research in past programs. Particularly, these items include thrusters for maneuver in space, thermal protection systems and gliding to a landing from a suborbital flight path.

The SCREMAR will require a means to maneuver in space, especially if it is going to dock with several satellites for retrieval, repair, and ASAT. Of essential importance is how much latitude the SCREMAR will have while maneuvering in LEOs. It is an extremely difficult task with limited maneuverability because of the proximity to the earth's atmosphere. Nevertheless, it can be accomplished by placing small thrusters at various points on the SCREMAR. They will also assist in maneuvering the TAV/orbiter into the proper position for reentry.

Thermal protection systems have been studied extensively. The capability to use heat absorbent tiles for reentry has been successfully demonstrated with the shuttle; although a similar concept might not be recommended for the SCREMAR. Nevertheless, a significant advancement in TPS would not need to be made for the SCREMAR to accomplish its mission other than what is required for the SHAAFT. This topic is also discussed further in chapter 5.

The ability to glide to a horizontal landing on a conventional runway has also been demonstrated by the shuttle. The capability just needs to be improved so that global range to any conventional runway can be achieved from a suborbital flight path.

SCREMAR Vehicle Concepts

The design of the SCREMAR TAV/orbiter concept is driven primarily from the environments it must endure as well as the multiple mission profiles and the respective requirements. Increased cost benefits can be realized by increasing the vehicle's flexibility for multiple missions, using common logistics and operational procedures with other systems, using the existing infrastructure for support, and designing critical technologies in conjunction with other programs, such as the SHAAFT and SHMAC. A schematic of the SCREMAR TAV/orbiter concept can be seen in figure 4-2.

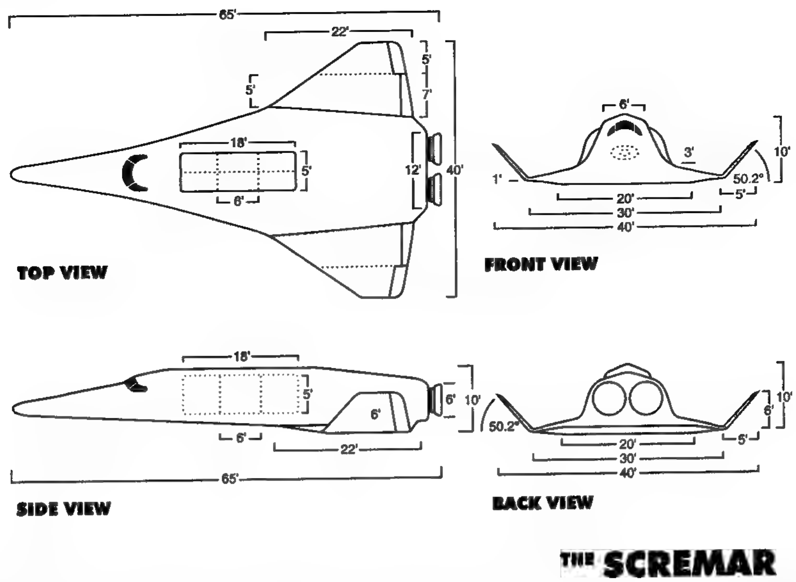


Figure 4-2. Space Control with a Reusable Military Aircraft (SCREMAR)

The SCREMAR is aerothermodynamically designed as a TAV/orbiter that piggybacks aboard the SHAAFT to a release point of Mach 12 at 100,000 feet where it then separates and uses two rocket engines to boost up to orbit. It can carry a 3,000-pound payload to orbit, roughly the size of three six feet x six feet x six feet, 1,000-pound satellites. The cargo bay is six feet x 18 feet x six feet. With a modular cargo bay integration, payloads could vary anywhere from tools to satellites to weapons systems. Upon returning to the atmosphere, the TAV/ orbiter would have the ability to reach and land on any Class A conventional runway worldwide. The design is simple enough so all that needs to be done once it returns is loaded with the new prepackaged payload, refueled, and reloaded onto the SHAAFT for another mission. Of course, due to the changing needs, the US has in the operational space environment versions that could be developed for both piloted and unpiloted vehicles.

As previously mentioned, the SCREMAR TAV/orbiter concept is roughly the size of an F-15. It is 66 feet in length and a total wingspan of 40 feet. It has an inverse-cokebottle type of shape that is similar in some respects to that of a lifting body or waverider concept. The wings themselves are fairly short, being only seven feet long each with a slight anhedral but rounded underside to produce a detached shock wave during reentry. Other concepts could have the wings with a slight dihedral and keeping everything else the same. Studies would need to be conducted on which design would be the most beneficial in terms of heating during reentry to the atmosphere, which provides the better lift to drag ratio in order to ensure global range from a suborbital flight path, and which is easier to integrate with the SHAAFT. Studies may also need to be conducted as to whether having the SCREMAR piggyback on top of the SHAAFT (as considered for this report) or whether it might be more beneficial to have the SCREMAR stored inside or underneath the SHAAFT, similar to the Beta concept.[5]

Considering the vertical stabilizer component of the wings, then each wingspan could actually be considered to be 12 feet. This is due to the fact that the vertical fins are actually canted at roughly 50° from the edges of the wings themselves. The reasoning for placing these vertical stabilizers in such

a manner is so that lateral-directional stability can be maintained throughout the high angles of attack that occur during reentry as well as help lower the q_∞'s. This is why the vertical stabilizer of the shuttle had to be enlarged; it was not very effective at the high angles of attack the shuttle encountered during reentry since it was directly blocked from the airflow by the body. Since there is no inlet for an airbreathing portion of the engine, the entire body configuration can be even more aerothermodynamically designed to support the mission.

There are two rocket engines that would provide enough thrust to get the spacecraft to orbit. There would also be various other thrusters along the body so that the SCREMAR TAV/orbiter could maneuver in orbit. Roughly 75 percent of the TAV/orbiters gross takeoff weight would consist of fuel which would be loaded throughout the entire body, maximizing the available volume. The only areas that would not contain fuel would be the cargo bay, cockpit, and the nose forward of the cockpit where all of the electronics would be placed. As previously mentioned, the density of the fuel as well as the I_{SP} are critical in maintaining the ideal size and weight of the spacecraft. Studies as to which fuels are the most efficient in terms of both I_{SP} and density are discussed further in chapter 5 as well as other important design considerations.

Component Summary

The SCREMAR TAV/orbiter concept has the capability to fulfill all of the tenets of aerospace power: Force Enhancement, Force Support, Aerospace Control, and Force Application. It can perform the missions of spacelift, on-orbit support, counterspace, and possibly strategic attack and reconnaissance. It provides a direct contribution to the missions of C^3I operations and counterinformation operations which are accomplished by the satellites it deploys. Refinements may also be used as part of a strategic attack and combat support operations. The use of a small TAV/orbiter, such as SCREMAR, allows for responsive, reliable, flexible access to space in all situations that are crucial to controlling and exploiting space.

The technologies needed for the SCREMAR should be developed in conjunction with the SHAAFT and SHMAC and from other similar programs to reduce time and costs. The infrastructure for supporting the SCREMAR should be developed from existing infrastructures. Because of the integrated nature of the SCREMAR with the SHAAFT, an integrated infrastructure should also be developed. This is because the SCREMAR functions operationally by means of the SHAAFT. Maintenance and other ground operations should be able to be accomplished within the times of what is already required for today's fighters.

There is also a need for standardization among launch vehicles and payload interfaces. In reducing planning, preparation, and turnaround times, the payload and spacecraft should be able to be prepared in parallel. The infrastructure should be able to allow the SHAAFT/SCREMAR to be launched on demand from a quick-reaction alert status while also allowing for the use of the widest number of bases possible. The infrastructure should be designed so that the SHAAFT/SCREMAR can function operationally similarly to today's aircraft.

There is no doubt that space is going to be the battlefield of tomorrow. The SCREMAR TAV/orbiter concept is designed to fulfill a vital role in maintaining control over that battlefield. It is intended to build off of the technologies and infrastructures that already exist or are in the process of being developed. Because of the simplicity of the SCREMAR and the reliance on near-term technologies, a significant breakthrough in technological achievement will not be required. This makes the development costs cheaper and the development time shorter. The SCREMAR, or similar vehicle, is destined to become a mainstay in the fleet of the US Air Force's vehicles. It is the

capabilities of such a vehicle that will ensure that the US is able to control and exploit space for years to come through reliable, flexible, routine access to space. This concept will **enable the United States to Scream into the Future!**

Notes

1. R. M. Zubrin and M. B. Clapp, "An Examination of the Feasibility of Winged SSTO Vehicles Utilizing Aerial Propellant Transfer: AIAA 94-29-23, 30th Joint AIAA/ASME/SAE/ASEE Joint Propulsion Conference, Indianapolis, Indiana, June 1994.

2. P. R. Gord, K. J. Langan, and M. E. Stringer, "Advanced Launch Vehicle Configurations and Performance Trades" (Paper from AGARD Conference Proceedings No. 489, Space Vehicle Flight Mechanics).

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4. Ibid.

5. Ibid.

Chapter 5

Critical Technology Requirements

Cruise Phase Velocity Study: The Driving Force

Defining the mission of SHAAFT was crucial to determining what type of vehicle was required. Similarly, defining the cruising velocities is vital to determining generic vehicle size, shape, performance, and supporting elements in the attack mission. This study considered two Mach numbers (eight and twelve) at which to fly. These two Mach numbers represent the best means in which to achieve the desired survivability. Mach eight characterizes the highest velocity in which endothermic hydrocarbons can be effective in scramjet engines, while being used as a coolant for aircraft surface skins. Mach 12 requires cryogenic fuels, such as liquid hydrogen, that can be used as an active coolant to accommodate extreme aircraft heating. However, active cooling requires a great deal of pipes, gaskets, and seals which must be maintained. This report assumes that material strengths will be great enough by the year 2025 (as will be discussed later) such that this type of cooling will not be necessary. Therefore, Mach 12 appeared to be the best design choice.

One advantage of Mach 12 flight involves the usage of current technology. Although developing cryogenic facilities for the SHAAFT would cost money, much of the technology exists for handling mass quantities of liquid or even slush hydrogen. Furthermore, with slush hydrogen, SCREMAR deployment would occur at a higher velocity, increase satellite payload capability or increasing the orbital altitude.

Table 2 summarizes the positive and negative points of limiting the Mach number to eight. Table 3 summarizes the same points for Mach 12. Overall, the advantages of Mach 12 flight appeared much greater than Mach eight and resulted in their incorporation into the SHAAFT. These key benefits include the reduction of the logistics arm required to support an allied attack on foreign land, the increased survivability, and expedient nature of attack. Also, a higher range results from higher velocity, thus conserving fuel.

While some parts of the missile design already exist, much research and development is required in other areas. This is particularly true in the case of the scramjet propulsion system which allows the missile to sustain Mach eight flight. One design challenge is sizing the combustion chamber. It must be long enough to allow adequate air and fuel mixing and combustion within the engine. For example, flow going through a 15-foot-long missile at Mach two (2,000 fps) will be contained within the scramjet chamber for approximately 0.007 seconds. This is an incredibly short time and does not allow for efficient mixing and combustion of all the fuel and air in the chamber of the scramjet using conventional fuel mixers and igniters.[1]

While new rocket fuels are not a must, it would certainly be desirable to have fuels available with higher specific impulses (I_{SP}). These are particularly needed for the ground and sea-launched versions since they will have to be accelerated from a standstill at ground level and will therefore not have the speed and altitude advantages of the air-launched versions.

Structurally, the missile will have to withstand the high initial acceleration of the rocket boost phase and maneuvering en route to the target. The average load factor in the acceleration phase is nine g's. This is a consideration since it is desirable to keep

Table 2

Parameters Considered for the Supersonic/Hypersonic Attack Aircraft (SHAAFT) at Mach Eight Flight

Pros	Cons
* Hypersonic vehicles powered by air-breathing propulsion systems with endothermic hydrocarbon fuels should be possible with reasonable advances in the technology of endothermic hydrocarbon fuels and in dual-mode ramjet/scramjet combustors. * The increased density of endothermic hydrocarbons means that less volume is required for fuel. As a result, it is easier to generate aerodynamically efficient configurations. * Endothermic hydrocarbons are easier to store and easier to transfer. This simplifies base operations and preflight activities. It probably also saves on training of ground personnel relative to the safe handling of fuels. These features also simplify transporting personnel and supplies to a non-CONUS recovery base. * Since the SHMACs (the standoff weapons to be delivered by the SHAAFT) fly at Mach eight, a flight Mach number of eight for the SHAAFT presents no problems relative to the deployment of these weapons.	* Endothermic hydrocarbons have lower specific impulse and lower cooling capacity than cryogenics (liquid hydrogen/liquid oxygen). As a result, if one uses endothermic hydrocarbons, the range is decreased and the time of flight to the target area is increased. * Preliminary studies have shown that the Mach number at which the SCREMAR (the TAV) is staged has a signficant impact on the weight and the size of the TAV. This also affects the size and number of satellites that can be carried to orbit. Thus, it is possible that features which produce savings on the vehicle and on the infrastructure to support the SHAAFT may increase the cost of the SCREMAR and the cost of getting payloads to space. The trade studies conducted in support of the design of the integrated, multivehicle weapons system should consider the interdependence of such phenomena.

Table 3

Parameters Considered for the Supersonic/Hypersonic Attack Aircraft (SHAAFT) at Mach 12 Flight

Pros	Cons
* Aircraft is much more survivable. * Pilot fatigue is reduced by cutting the total amount of flight time—in the worst-case scenario, this could save the life of the SHAAFT. * Decreases time to target (response time). * Increases range due to increased specific impulse of slush hydrogen versus endothermic hydrocarbons. * Increased velocity results more design options for SCREMAR access-to-space vehicle. * It is more advantageous to launch the SHMAC missile from a higher speed and decelerate rather than low speed and a need to accelerate (like an F-15 launch). * Technology already exists to handle mass quantities of cryogenic fuels.	* Increased surface heating poses several problems. Material concerns, thermal expansion, and aero-acoustic problems all increase in magnitude. If active cooling is used, fuel pumps, gaps, and seals will drive up complexity and cost of the design. * Base infrastructure, logistical support must be created at the SHAAFT base to support cryogenic fuels, which are inherently more expensive and complex. * Low density of slush hydrogen means a larger fuel volume—this increases drag, which increases the required fuel, which drives up the size of vehicle even further.

the overall weight of the missile as low as possible.

Better high-speed guidance, targeting, and control systems will also need to be developed if the SHMAC's capability is to be maximized. For example, it is believed that the SHMAC could be used in 2025 to intercept ballistic missiles in flight, although with current technology, this is not very feasible. However, with all of the research currently going on in this area, it is very possible that this mission will be one of the SHMAC's.

Thermal Protection Systems

The expected temperature extreme on the SHMAC is approximately 3,400°R for a leading edge radius of 1.0 in. This was based on calculations of the stagnation point heating rate as it varies with the nose radius and altitude of the vehicle.

The variant used in the shuttle is LI-900 (Lockheed Insulation, nine pounds per cubic foot) and LI-2200 (22 pounds per cubic foot) which are used to cover 50 percent of the exterior of the shuttle orbiter. They can withstand temperatures as high as 2,300°F. The black radiative coating applied to these silica tiles allows 90 percent of the heat generated upon reentry to be radiated back out into the atmosphere. The temperatures on the shuttle's aluminum skin never exceed 350°F.

FRCI-12 was used to replace LI-2200 and by so doing reduced the shuttle weight by 1,000 pounds. FRCI stands for Fibrous Refractory Composite Insulation and weighs 12 pounds per cubic foot. It is just as strong as LI-2200. It is tested up to 2,400°F with gradual reduction in strength beginning at approximately 1,600°F.

LI-900 has no organic constituents that will outgas to contaminate scramjet combustion chamber parts or equipment. It also does not weaken with increasing heat loads. It can withstand 2,500°F and does not degrade until 3,100°F. It is inert, therefore it does not react with most fluids and substances. Any of these variants will be acceptable for use on the SHMAC.

Flexible external insulation (FEI) was developed as an element for HERMES. Produced in blankets which bond to the primary structure. The bonding surface must not exceed 650°C during normal flight conditions, a maximum of 800°C is permitted for short periods of time in case of an emergency. FEI will be dimensioned such that its back surface does not normally exceed 200°C. It is sensitive to acoustic loads and tends to exhibit aerodynamic flutter. The density of it is 2,200 Kg/m^3.

Honeycomb TPS is applied in panels. It is generally used for hot structures and heat shields which rely on thermally resistant materials and connections between core and cover sheets. Honeycomb TPS is attached by screw connections through the upper plate which have to be protected by ceramic plugs. This structure must be vented to allow for pressure equalization due to altitude and high speeds. The density of this material is $4.43 g/m^3$.

Multiwall TPS is being developed at NASA. This consists of dimple foils made of superplastic forming and shear foils. Used for the heat shield and at the panel back face. Upper surface is coated with highly emissive Al_2O_3 . This construction principle can be used with different metallic alloys depending on the temperature range desired. Density: 4.43 g/m^3 to 8.98 g/m^3.

Ceramic shingles are associated with the HERMES program. This consists of intermediate multiscreen insulation with ceramic and coated screens separating individual layers from quartz silica fibers. Panel mass depends on material thickness which results from a trade-off between manufacturing technology and mechanical panel design. This material, which is still under development in France and Germany, has a density of 2.2 g/cm^3.

A new thermal protection technology currently under development by the Ames Research Center division of the National

Aeronautics and Space Administration is ultrahigh temperature ceramics (UHTC). These ceramics are generally formulated from dibromide compounds. Experiments have validated these ceramics' ability to withstand temperatures up to 3,822°R.

In order to choose a proper thermal protection system, the trade-off between cost for a UHTC against the effect an ablator will have on aerothermodynamic performance must be weighed. The advantage of the UHTC is that the shape of the leading edges of the missile will not change throughout the course of the flight. A disadvantage is its high cost due to its recent development as a revolutionary technology. Although the cost of ablators is attractive, the drawback is the changing shape of leading edges caused by the ablator burning off throughout the course of the flight and any possible effects this may have on the control and propulsion system of the missile.

Conclusion

For all of the possibilities described throughout this paper, the US needs a flexible, robust, easily planned and executed capability for global reach/global power and for access to space. The SHAAFT would serve as a mobile platform for deploying a wide range of UAV assets. The SHMACs would destroy key targets, including space ports, communications centers, computer centers, time critical targets, and so forth. The SCREMAR would serve the many wartime applications which require access to space. Thus, the integrated S^3 (SHAAFT, SHMAC, SCREMAR) weapons system that has been described can perform Counterspace tasks for Aerospace Control, tasks of Strategic Attack, of C^2 Attack, of Interdiction for Force Application, Aerospace Replenishment and Space Lift tasks for Force Enhancement, and On-Orbit Support for Force Support.

Furthermore, it is quite possible (perhaps, even likely) that, at the outset of hostilities, our adversary has created significant damage to our space launch complexes (just as we did to theirs with our SHAAFT mission), leaving the United States in an *Infrastructure Poor* situation—the term is attributed to Maj (sel) M. B. Clapp. Thus, we need to be able to launch our global-range air and space missions from conventional military bases. The integrated, hypersonic weapons system described in this paper allows the US to accomplish a diverse set of missions, with a highly survivable, lethal weapon system capable of deterring and/or punishing adversaries anywhere in the world.

There is still room for further research and development. The first among these areas is the need for study on propulsion systems and the technology development for scramjet/rocket engines. Other areas to consider for further study include enhanced and improved thermal protection systems. Research developments are expected in finding ways to communicate through hot plasma boundary layers for continual data uplinks.

Also included in the need for further research are understanding shock/shock interactions at high speeds that the weapons systems would be operating at. Advances in the capabilities and accuracy of CFD are needed to explore the flight regimes that S^3 will operate within.

It is of importance to note that most of these technologies have already been developed or are in the process of being developed. It is also important to realize that each advancement taken in a particular area aids in the development of not just one weapons unit, but to the entire S^3 weapons platform, as well as other technology areas that will be important to the growth and survival of the US in the world of 2025.

Note

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StrikeStar 2025

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Executive Summary

The United States military of the year 2025 will need to deal with a wide variety of threats in diverse parts of the world. It will be faced with budgetary restraints that will dictate system trades favoring those military elements that offer utility over a wide spectrum of conflict and add to the ability to project power over long distances. The United States military of the year 2025 will also exist in a social and political environment that will dictate the need to minimize United States personnel losses and enemy collateral damage.

An opportunity exists to exploit planned advances in intelligence, surveillance, reconnaissance, and the development of unmanned aerial vehicles (UAV) to address future military needs. Through all-source, coordinated intelligence fusion, it will be possible to supply the war fighter with all-weather, day or night, near-perfect battle-space awareness. This information will be of precision targeting quality and takes advantage of multiple sources to create a multidimensional view of potential targets. Early in the twenty-first century, reconnaissance UAVs will mature to the extent that reliable, long-endurance, high-altitude flight will be routine, and multiple, secure command and control communications links to them will have been developed.

The obvious extension of these developments is to expand UAV use to include lethal missions. In 2025, a stealthy UAV, we refer to as "StrikeStar," will be able to loiter over an area of operations for 24 hours at a range of 3,700 miles from launch base while carrying a payload of all-weather, precision weapons capable of various effects. Holding a target area at continuous risk from attack could result in the possibility of "air occupation." Alternatively, by reducing loiter time, targets within 8,500 miles of the launch and recovery base could be struck, thus minimizing overseas basing needs.

A concept of operations for this UAV will include various operation modes using the information derived from multiple sources to strike designated targets. In developing and fielding this type of a weapon system, a major consideration will be carrying weapons aboard unmanned vehicles. However, the StrikeStar UAV concept has the potential to add new dimensions to aerial warfare by introducing a way to economically and continuously hold the enemy at risk from precision air attack.

Chapter 1

Historical Development and Employment

Unless you plan your strategy and tactic far ahead, unless you implement them in terms of weapons of tomorrow, you will find yourself in the field of battle with weapons of yesterday.

—Alexander de Seversky

The United States Air Force will remain actively engaged in all corners of the globe and at all levels of the conflict spectrum. Yet at the same time, the military budget is decreasing, overseas bases are closing, and there is political and social pressure to keep United States and adversary casualties to a minimum in any future conflicts. The situation, as described, is unlikely to change much in the future. As the Air Force adapts to this new set of realities and meets it commitments to the nation, it will need to look at new ways and methods of doing business. One of the most promising future possibilities is the increased use of unmanned aerial vehicles (UAV) to perform tasks previously accomplished by manned aircraft. Unmanned aircraft have the potential to significantly lower acquisition costs in comparison with manned alternatives, thus enabling the fielding of a more robust force structure within constrained budgets. Unmanned aircraft can also be tasked to fly missions deemed unduly risky for humans, both in an environmental sense (i.e., extremely high-altitude or ultra long-duration flight) as well as from the combat loss standpoint. The Department of Defense (DOD) recognized the potential value of the UAV through its support of the Defense Airborne Reconnaissance Office's (DARO) advanced concept technology demonstrations (ACTD) of a family of long-endurance reconnaissance UAVs. However, the DARO UAVs, along with other improvements in reconnaissance and communications, will lead to even greater possibilities in the use of UAVs to project precision *aerospacepower*[1] to all parts of the world and to remain engaged at any level of conflict.

The Early and Cold War Years

The use of UAVs is not a new experience for the United States armed forces or those of many other states. The German use of the V-1 in World War II showed that unmanned aircraft could be launched against targets and create a destructive effect.[2] Unfortunately, the V-1 was a "use and lose" weapon. Once launched, it was designed to destroy itself as well as the target. In the 1950s, the United States developed an unmanned intercontinental-range aircraft, the Snark. Designed to supplement Strategic Air Command's manned bombers in nuclear attacks against the Soviet Union, this unmanned aircraft also destroyed itself as it destroyed the target. In effect, these were precursors of today's cruise missile.

In the United States, the UAV has normally been associated with the reconnaissance mission and designed to be a recoverable asset for multiple flight operations. The remotely piloted vehicles (RPV) of the early 1960s were developed in response to the perceived vulnerability of the U-2 reconnaissance aircraft, which had been downed over the Soviet Union in 1960 and again over Cuba in 1962.[3] "Red Wagon" was the code name for a 1960 project by Ryan Aeronautical Company to demonstrate how its drones could be used for unmanned, remotely guided photographic

reconnaissance missions.[4] As early as 1965, modified Ryan Firebee drones were used to overfly China with some losses experienced.[5]

In 1962, in conjunction with the development of the Central Intelligence Agency's manned A-12 (similar to the SR-71 Blackbird) reconnaissance aircraft, Lockheed began development of the D-21 supersonic reconnaissance drone (fig. 1-1). The D-21 (code-named "Tagboard") was designed to be launched from either the back of a two-seat A-12 (designated M-12 for this project) or from under the wing of a B-52H.[6] The drone could fly at speeds greater than Mach 3.3, at altitudes above 90,000 feet, and had a range of 3,000 miles.[7] At the end of the D-21's mission, the reconnaissance and navigation equipment as well as the exposed camera film could be parachuted away from the airframe and be recovered by a specially equipped aircraft.[8] The project was canceled in 1971 due to numerous failures and the high cost of operations.[9]

The best known United States UAV operations were those conducted by the United States Air Force during the Vietnam War. Ryan BQM-34 (Ryan designation: Type 147) "Lightning Bug" drones were deployed to the theater in 1964.[10] From the start of operations in 1964 until missions were terminated in 1975, 3,435 operational drone sorties were flown in Southeast Asia by the Strategic Air Command's 100th Strategic Reconnaissance Wing.[11] These air-launched UAVs flew both high (above 60,000 feet) and low (below 500 feet) altitude missions. Mission durations were as long as 7.8 hours. Types of missions flown included photo reconnaissance, leaflet dropping, signals intelligence collection, and the laying of radar-confusing chaff corridors to aid penetrating strike aircraft.[12] The average life expectancy of a drone in Southeast Asia was 7.3 missions with one aircraft, the Tomcat, flying 68 missions before being lost (fig. 1-2). Recovery rates for operational unmanned aircraft in Southeast Asia were approximately 84 percent with 2,870 of the 3,435 sorties recovered.[13]

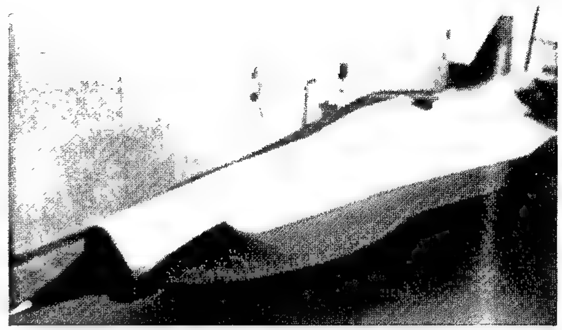

Figure 1-1. D-21 Tagboard

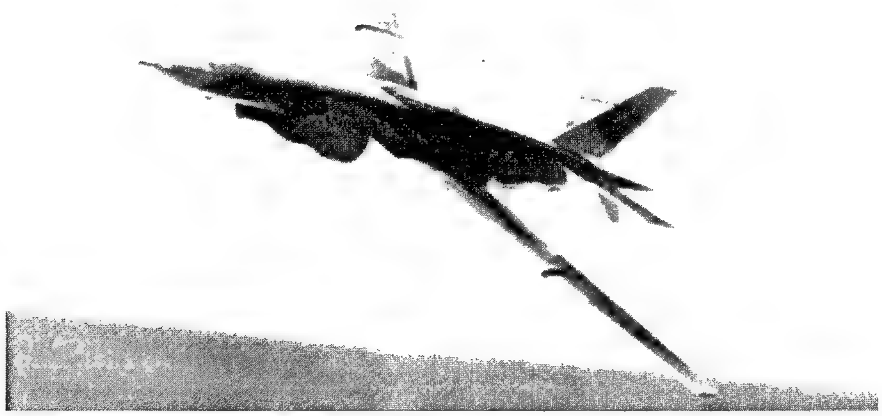

Figure 1-2. BQM-34 UAV, Tomcat

In addition to the reconnaissance role, Teledyne Ryan also experimented with lethal versions of the BQM-34 drone. In 1971 and 1972, drones were armed with Maverick missiles or electro-optically guided bombs "Stubby Hobo" in an attempt to develop an unmanned defense suppression aircraft to be flown in conjunction with manned strike aircraft (fig. 1-3). The thinking behind this project was that an unmanned aircraft ". . . doesn't give a damn for its own safety. Thus every unmanned bird is a potential Medal of Honor winner!"[14]

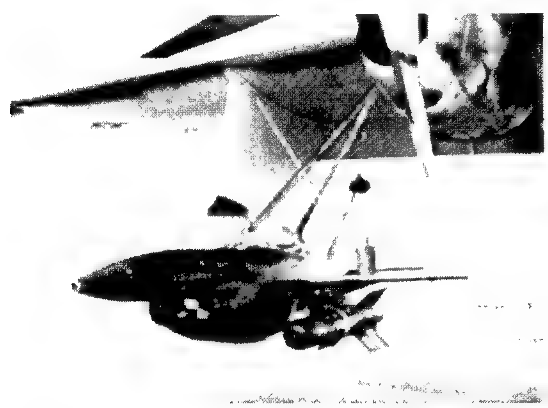

Figure 1-3. BQM-34 UAV with "Stubby Hobo"

The Israelis effectively used UAVs in 1973 and 1982. In the 1973 Yom Kippur War, the Israelis used UAVs as decoys to draw antiaircraft fire away from attacking manned aircraft. In 1982, UAVs were used to mark the locations of air defenses and gather electronic intelligence information in Lebanon and Syria. During the war, the Israelis used UAVs to continually monitor airfield activities and use the information that was gathered to alter strike plans.[15]

The Gulf War and Its Aftermath

The United States "rediscovered" the UAV in the Gulf War. The Pioneer UAV (fig. 1-4) was purchased by the Department of the Navy to provide inexpensive, unmanned, over-the-horizon targeting, reconnaissance, and battle damage assessment (BDA).[16] The Army purchased the Pioneer for similar roles and six Pioneer systems (three Marine, two Navy, and one Army) were deployed to Southwest Asia to take part in Desert Storm. During the war, Pioneers flew 330 sorties and more than 1,000 flight hours.[17]

In the aftermath of the Gulf War, the United States began to look more closely at the use of the reconnaissance UAV and its possible use to correct some of the reconnaissance shortfalls noted after the war. Space-based and manned airborne reconnaissance platforms alone could not satisfy the war fighter's desire for continuous, on-demand, situational awareness information.[18] As a result, in addition to tactical UAVs, the United States began to develop a family of endurance UAVs that added a unique aspect to the UAV program.[19] Three different aircraft comprise the endurance UAV family.

The Predator UAV is an outgrowth of the CIA-developed Gnat 750 aircraft (fig. 1-5).[20] Also known as the Tier II, or medium altitude endurance (MAE) UAV, the Predator is manufactured by General Atomics Aeronautical Systems and costs about $3.2 million per aircraft.[21] It is designed for an endurance of greater than 40 hours, giving it the capability to loiter for 24 hours over

Figure 1-4. Pioneer on Sea Duty

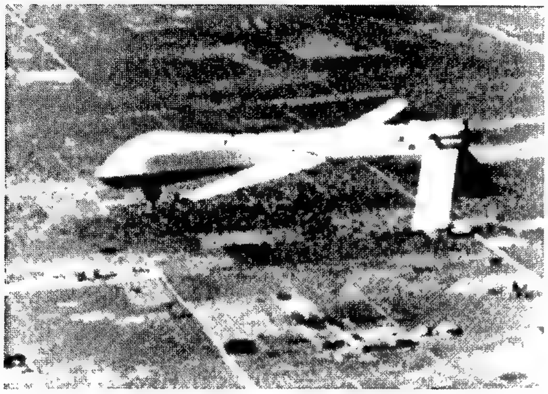

Figure 1-5. The Predator UAV

an area 500 miles away from its launch and recovery base.[22] It is powered by a reciprocating engine giving it a cruise speed of 110 knots, loiter speed of 75 knots, ceiling of 25,000 feet, 450 pound payload, and a short takeoff and landing capability. The Predator carries an electro-optical (EO) and infrared (IR) sensor and was recently deployed with a synthetic aperture radar (SAR) in place of the EO/IR sensor. The Predator is also unique in its ability to collect full-rate video imagery and transmit that information in near real time via satellite or line-of-sight (LOS) data link.[23] The Predator first deployed to Bosnia in 1994 and has since returned there with two combat-related losses (see appendix A).

A higher performance vehicle is the Teledyne Ryan Aeronautical Conventional High Altitude Endurance (CHAE) UAV (fig. 1-6). Referred to as the Tier II+, or Global Hawk, it is designed to fulfill a post-Desert Storm requirement of performing high-resolution reconnaissance of a 40,000 square nautical mile area in 24 hours. The Global Hawk is designed to fly for more than 40 hours giving it a 24-hour loiter capability over an area 3,000 miles from its launch and recovery base. It will simultaneously carry a SAR and an EO/IR payload of 2,000 pounds and operate from conventional 5,000-feet runways. The aircraft will cruise at altitudes above 60,000 feet at approximately 340 knots.[24] Tier II+ is scheduled to fly in late 1997 and meet a price requirement of $10 million per unit.

The low observable high altitude endurance (LOHAE) UAV (Tier III- or DarkStar) is the final member of the DARO family of endurance UAVs (fig. 1-7). DarkStar is manufactured by Lockheed-Martin/Boeing and is designed to image well-protected, high-value targets with either SAR or EO sensors.[25] It will be capable of loitering for eight hours at altitudes above 45,000 feet and a distance of 500 miles from its launch and recovery base. DarkStar can be flown from runways shorter than 4,000 feet. DarkStar's first flight occurred in March 1996.[26] This UAV is also designed to meet a $10 million per aircraft unit fly-away price. DARO's new endurance UAVs, along with manned airborne reconnaissance aircraft, are designed to meet Joint Requirements Oversight Council (JROC) desires for the development of reconnaissance systems that are able to ". . . maintain near perfect real-time knowledge of the enemy and communicate that to all forces in near-real time."[27] DARO's goal is "extended reconnaissance," which is "the ability to supply responsive and sustained intelligence data from anywhere within enemy territory, day or night, regardless of weather, as the needs of the war fighter dictate."[28] The objective is to develop by the year 2010, a reconnaissance architecture that will support the goal of "extended reconnaissance."

Figure 1-6. The Global Hawk UAV

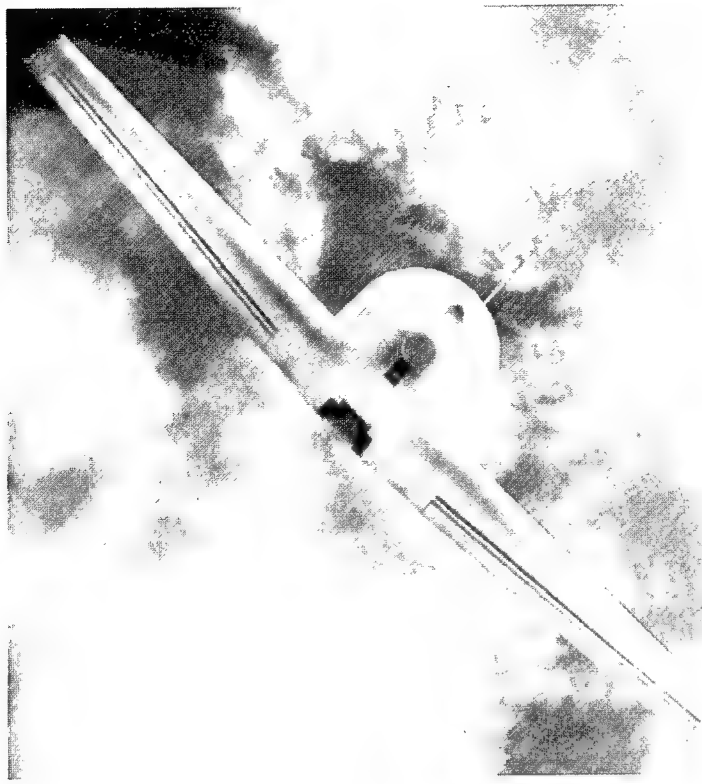

Figure 1-7. The DarkStar UAV

To do this, DARO will consolidate platforms, introduce endurance and tactical UAVs, emphasize all-weather sensors as well as multispectral optical sensors, improve information systems connectivity to the war fighter through robust line-of-sight and over-the-horizon communications systems, produce scaleable and common-use ground stations, and focus on the benefits of interdisciplinary sensor cueing.[29] In conjunction with spaceborne and other surveillance assets, this objective architecture will provide the war fighter and command elements with near-perfect battlespace awareness.

The seamless integration of airborne and spaceborne reconnaissance and surveillance assets, along with robust, on-demand communications links, coupled with the experience in long-endurance, high-altitude UAVs made possible by current DARO efforts, will lead to the next step in the development and employment of unmanned aerial vehicles—the long-endurance, lethal, stealthy UAV. A possible name for this new aircraft could be "StrikeStar," and we will refer to it by that name throughout this paper.

StrikeStar will give the war fighter a weapon with the capability to linger for 24 hours over a battlespace 3,700 miles away, and, in a precise manner, destroy or cause other desired effects over that space at will. Bomb damage assessment will occur nearly instantaneously and restrike will occur as quickly as the decision to strike can be made. StrikeStar will allow continuous coverage of the desired battle space with a variety of precision weapons of various effects which can result in "air occupation"—the ability of *aerospacepower* to continuously control the environment of the area into which it is projected. The next chapter explores the requirements that drive the StrikeStar UAV concept.

Notes

1. The term "aerospacepower" is used as one would normally use the word "airpower" and reflects the inseparability of air and space assets in 2025. In 2025, there will be no airpower and space power, only aerospacepower.

2. Dr Michael H. Gorn, *Prophecy Fulfilled: Toward New Horizons and Its Legacy* (Air Force History and Museums Program, 1994), 28–35.

3. Paul F. Crickmore, *Lockheed SR-71 - The Secret Missions Exposed* (London: Osprey Aerospace, 1993), 9,16.

4. William Wagner, *Lightning Bugs and Other Reconnaissance Drones* (Fallbrook, Calif.: Aero Publishers, Inc., 1982), 15.

5. Ibid., 115.

6. Jay Miller, *Lockheed's Skunk Works: The First Fifty Years* (Arlington, Tex.: Aerofax, Inc., 1993), 134–35; Ben R. Rich, *Skunk Works* (N.Y.: Little, Brown and Co., 1994), 267.

7. Miller, 141.

8. Crickmore, 38.

9. Rich, 269.

10. Lt Col Dana A. Longino, *Role of Unmanned Aerial Vehicles in Future Armed Conflict Scenarios* (Maxwell AFB, Ala.: Air University Press, December 1994), 3; Wagner, 52.

11. Wagner, 52, 200.

12. Ibid., 197.

13. Ibid., 200, 213.

14. Ibid., 185.

15. Ibid., 6.

16. *Unmanned Aerial Vehicles*, Defense Airborne Reconnaissance Office Annual Report (Washington, D.C., August 1995), 5.

17. Longino, 9.

18. *Unmanned Aerial Vehicles*, 7.

19. Steven J. Zaloga, "Unmanned Aerial Vehicles," *Aviation Week & Space Technology*, 8 January 1996, 87.

20. Ibid.

21. David A. Fulghum, "International Market Eyes Endurance UAVs," *Aviation Week & Space Technology*, 10 July 1995, 40–43.

22. *Unmanned Aerial Vehicles*, 27.

23. David A. Fulghum, "Predator to Make Debut Over War-Torn Bosnia," *Aviation Week & Space Technology*, 10 July 1995, 48.

24. Fulghum, 43.

25. Zaloga, 90–91.

26. "Tier III- DarkStar First Flight Video," *Lockheed-Martin Skunkworks*, 29 March 1996.

27. *Airborne Reconnaissance Technology Program Plan - Executive Summary*, Defense Airborne Reconnaissance Office (Washington, D.C., February 1995), 2.

28. *Unmanned Aerial Vehicles*, 1.

29. Ibid., 4.

Chapter 2

The Need for Strike Unmanned Aerial Vehicles

What we need to develop is a conventional deterrence force, similar to our nuclear triad, that we can project and sustain over long distances.

—Gen Ronald R. Fogleman

As 2025 approaches, the use of unmanned aerospace vehicles will be driven by sociocultural, geopolitical, and economic forces. Although it is impossible to see the future, some assumptions can be developed about the year 2025:

1. Americans will be sensitive to the loss of life and treasure in conflict.
2. The US economy will force its military to be even more cost-effective.
3. Technology will give potential enemies the ability to act and react quickly.[1]

These strategic assumptions create operational needs the US military must meet by 2025. UAVs are one cost-effective answer to those needs and have the potential for use across the spectrum of conflict. Although the need for advanced capabilities is continually emerging, this concept identifies constraints that create a demand for lethal UAVs in 2025 and a possible solution to that need. By 2025, limitations may cause gaps in US airpower and UAVs offer the ability to bridge them.

Current Forces

Currently, the triad of conventional aerospace forces consists of carrier-based aircraft, land-based strike aircraft, and CONUS-based, long-range bombers. While proven very effective in Desert Storm, this triad has several limitations.[2] First, the aircraft carrier fleet is limited. Naval aviation lacks stealthy vehicles and long-range systems.[3] Carriers will increasingly be called on for global presence missions, but cannot be everywhere at once.[4] Second, land-based fighters require forward basing, which could take days or even weeks to develop before employment. Finally, long-range manned bombers require supporting tankers, have limited loiter time over long distances, varying degrees of penetration capability, and can require up to 48 hours to prepare for strikes.[5] In 2025, these limitations will have a greater effect on US power projection as a result of two factors: the shrinking military budget and a smaller military force (fig. 2-1).[6]

The ripple effects of current US government budgetary problems are just beginning to affect US military force levels and strength. Tighter military budgets will continue through 2010, or longer, and fewer new strike aircraft purchases will result as costs increase.[7] Figure 2-2 represents a possible fighter force of 450 by the year 2025 and takes into consideration one of the alternate futures that might be faced.[8] It is likely that today's fighter force will be retired by 2018, the F-22 will begin entering retirement in 2025, and that there will be further reductions in the bomber fleet. These actions will result in a 2025 triad of conventional aerospace strike forces one fourth the size of the 1996 force.[9]

Unfortunately, the demands on this smaller force will not diminish. To be effective in 2025, our smaller conventional aerospace triad will require a force multiplier that will enable the US military to strike within seconds of opportunities. One way to achieve these results is to get inside our adversary's observation-orientation-

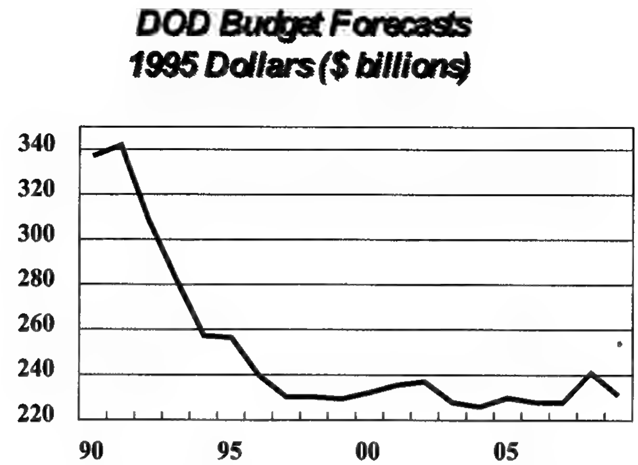

Figure 2-1. The Shrinking Military Budget

decision-action (OODA) loop while reducing the time required for us to observe, and then act.[10] The advent of the capability for dominant battlespace awareness allows us the ability to significantly reduce our observation, orientation, and decision phases of the loop.[11] Unfortunately, our current triad of conventional aerospace forces is time-limited in many scenarios due to deployment, loiter, risk, and capability constraints. The concept of a long-loiter, lethal UAV orbiting near areas of potential conflict could allow us to significantly reduce the OODA loop action phase. In fact, the entire OODA loop cycle could be reduced from days or hours to literally seconds.[12] The lethal UAV offers a variety of unique capabilities to the war fighter at the strategic, operational, and tactical levels of war.

The US strategic triad possesses the capability to hold other countries at risk with a very short (30 minute) response time, but unfortunately, this type of deterrence is only effective against forces similarly equipped. With the exception of current no-fly zones in Iraq and Bosnia, we normally do not have conventional

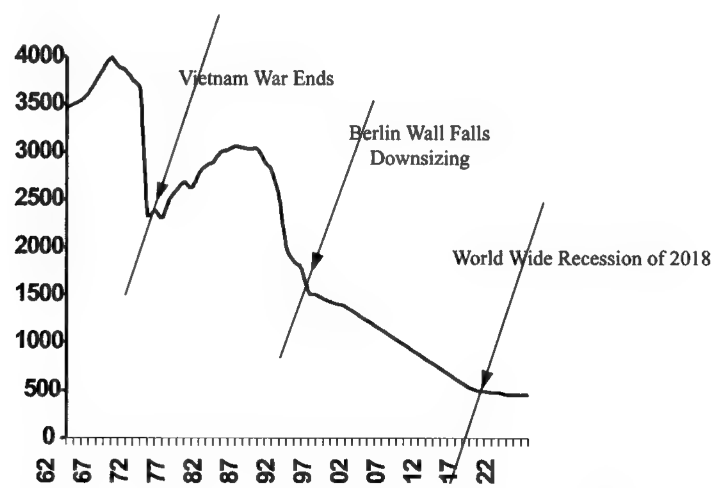

Figure 2-2. Fighter Force Projection for 2025

aerospace forces posed for immediate precision strike, nor do we have the capability to exercise this option beyond one or two theaters. Although no-fly zones in Iraq and Bosnia are considered successful operations, the operations tempo and dollar cost of maintaining this deterrence is high. In 2025, a smaller, conventional aerospace triad will be expected to react within seconds over the broad spectrum of conflict from military operations other than war (MOOTW) to major regional conflict (MRC); overcome improved enemy air defense systems; and meet demands for fewer pilot and aircraft losses, all without requiring extremely high operational tempos.[13] These expectations will demand the development of a force multiplier to overcome the current, conventional aerospace triad limitations.

Required Capability

The force multiplier required for 2025 conventional aerospace triad forces must be capable of exercising the airpower tenets of shock, surprise, and precision strike while reducing the OODA loop time from observation to action to only seconds. Also, this force must possess the capabilities of stealth for survivability and reliability for a life span equivalent to that of manned aircraft. Many possibilities exist across the spectrum of conflict. This paper develops the concept of a stealthy, reliable UAV capable of precision strike. StrikeStar could act as a force multiplier in a conventional aerospace triad one fourth the size of the 1996 force structure.

The StrikeStar UAV could add a new dimension to the war fighter's arsenal of weapons systems. In a shrinking defense budget, it might be a cheaper alternative to costly manned strike aircraft if today's high altitude endurance UAVs are used as a target cost guide. StrikeStar must rely on a system of reconnaissance assets to provide the information needed for it to precisely and responsively deliver weapons on demand. To save costs and minimize the risk of losing expensive sensors, StrikeStar itself should have a minimal sensor load. The robust, expensive sensors will be on airborne and space reconnaissance vehicles, feeding the information to the UAV. An air or ground command element located in the theater of operations or continental United States could receive fused reconnaissance data and use it to direct the StrikeStar to its targets. A secure, redundant, communications architecture would connect StrikeStar and the command element, but the communications suite could be rather minimal since the UAV would normally be in a receive-only mode to reduce detectability.

StrikeStar should have a minimum 4,000-pound payload so a variety of all-weather weapons could be employed by the UAV, depending on the target and the effect desired. Lethal weapons could include global positioning satellite (GPS)-guided, 250-pound conventional weapons that would have the effect of current 2,000-pound weapons. Nonlethal weapons such as "Stun Bombs" producing overbearing noise and light effects to disrupt and disorient groups of individuals could also be delivered. Target-discriminating, area-denial weapons, air-to-air missiles, and theater missile defense weapons could be employed to expand StrikeStar's potential applicability to other mission areas. Finally, the best lethal weapon for StrikeStar might be an all-weather directed-energy weapon (DEW) that could allow hundreds of engagements per sortie.

StrikeStar would be designed for tremendous range, altitude, and endurance capabilities. Cruising at 400 knots true airspeed, StrikeStar would have an unrefueled range of almost 17,000 nautical miles, thus minimizing the historical problems inherent in obtaining overseas basing rights that have limited our strategic choices. Translated into a loiter capability, StrikeStar could launch, travel 3,700 miles to an orbit area, remain there for 24 hours and then return to its original launch base. With a cruise altitude above 65,000 feet and a maximum altitude of 85,000 feet,

StrikeStar could fly well above any weather and other conventional aircraft. It would fly high enough to avoid contrails and its navigation would not be complicated by jet stream wind effects.

Such capabilities should easily be possible by 2025. Before the year 2000, today's Tier II+ UAV will have reached nearly the StrikeStar range/endurance and payload capabilities and the Tier III– will have demonstrated stealth UAV value. The issue then revolves around the use of such an unmanned capability and how such a capability could add value to *aerospace-power* of the twenty-first century. Ben Rich, a former president of Lockheed's "Skunk Works" saw the future of the unmanned strike vehicle:

> But even a leader able to whip up sentiment for "sending in the Marines" will find it dicey to undertake any prolonged struggle leading to significant casualties. . . . As we proved in Desert Storm, the technology now exists to preprogram computerized combat missions with tremendous accuracy so that our stealth fighters could fly by computer program precisely to their targets over Iraq. A stealthy drone is clearly the next step, and I anticipate that we are heading toward a future where combat aircraft will be pilotless drones.[14]

Coupled with the ability to reduce casualties, StrikeStar and its supporting reconnaissance and communications assets will add new meaning to what the Joint Chiefs of Staff call *precision engagement:*

> Precision engagement will consist of a system of systems that enables our forces to locate the objective or target, provide responsive command and control, generate the desired effect, assess our level of success, and retain the level of flexibility to reengage with precision when required. Even from extended ranges, precision engagement will allow us to shape the battlespace, enabling dominant maneuver and enhancing the protection of our forces.[15]

Milestones

Currently, technology is being developed to accomplish this concept. While the technology will exist by the beginning of the twenty-first century, transferring this technology from the laboratory to the battlefield will require reaching three new milestones in aerospace thinking.

First, US military leadership must be willing to accept the concept of lethal UAVs as a force multiplier for our conventional aerospace triad of 2025. They should not deny the opportunity for continued growth in this capability.[16] The issue revolves around the use of an unmanned capability and how such a capability could add value to *aerospacepower* of the twenty-first century.

Second, doctrinal and organizational changes need to be fully explored to ensure this new weapon system is optimally employed. In the context of a revolution in military affairs (RMA), developing a new weapon system is insufficient to ensure our continued prominence. We must also develop innovative operational concepts and organizational innovations to realize large gains in military effectiveness.[17]

Finally, a target date not later than 2022 should be set for this refined concept and supporting systems to be operational for combat employment. This will give the US military and contractors time needed to correct deficiencies, leverage new technological developments, and polish capabilities equivalent to or beyond the manned portion of the conventional aerospace triad.[18] The need will exist in 2025 for a cost-effective, reliable force multiplier for the US military aerospace forces. StrikeStar offers a unique combination of these three requirements and now is the time to begin working toward these milestones to meet conventional aerospace triad needs in 2025.

Notes

1. Gene H. McCall, Chairman USAF Scientific Advisory Board, presentation to the ***2025*** Study Group, Maxwell AFB, Ala., 6 September 1995.

2. Thomas A. Keaney and Eliot A. Cohen, *Gulf War Air Power Survey Summary Report* (Washington, D.C., 1993), 15.

3. John T. Correll, "Deep Strike," *Air Force Magazine*, April 1996, 2.

4. James A Lasswell, "Presence - Do We Stay or Do We Go?" *Joint Forces Quarterly*, Summer 1995, 84–85; Col Walter Buchanan, JCS/J3, "National Military Command Center," presentation to Air Command and Staff College, 27 February 1996.

5. Maj David W. Schneider, "Heavy Bombers Holding the Line," *Airpower Journal*, Winter 1994, 45–52.

6. Col William Jones, JCS/J8, "JROC and the Joint Warfighting Capabilities Assessment Process," presentation to Air Command and Staff College, 12 February 1996.

7. David R. Markov, "The Aviation Market Goes Global," *Air Force Magazine*, June 1995, 22–28. In this article Mr Markov paints a gloomy picture of total strike aircraft production worldwide due to lower defense budgets and rising costs.

8. "AF ***2025*** Alternate Futures: Halfs and Have Naughts," April 1996.

9. "A New Defense Industrial Strategy," *Airpower Journal*, Fall 1993, 18–22; Brian Green, "McCain's Rising Star," *Air Force Magazine*, April 1996, 9. In this article, Senator John McCain states, "It's obvious we're not going to maintain the force structure that was anticipated when the two-MRC scenario was designed."

10. John R. Boyd, "The Essence of Winning and Losing," presentation to the ***2025*** Study Group, Maxwell AFB, Ala., October 1995.

11. "Warfighting Vision 2010: A Framework for Change" (Fort Monroe, Va.: Joint Warfighting Center, 1 August 1995), 10–11.

12. Maj James P. Marshall, *Near-Real-Time Intelligence on the Tactical Battlefield*, (Maxwell AFB, Ala.: Air University Press, January 1994), 100. In this report, Maj Marshall proposes a wide range of target lifetimes ranging from several hours to one minute.

13. Clark A. Murdock, "Mission-Pull and Long-Range Planning," *Joint Forces Quarterly*, Autumn/Winter 94–95, 33. Mr Murdock identifies 12 operating environments, more than 60 military missions, and more than 200 critical tasks by the year 2011.

14. Ben R. Rich, *Skunk Works* (N.Y.: Little, Brown and Co., 1994), 340.

15. *Joint Vision 2010* (Washington, D.C., The Joint Chiefs of Staff, 1995), 9.

16. Jeffrey Cooper, Another View of Information Warfare: Conflict in the Information Age, SAIC, (Publication Draft for ***2025*** Study Group), 26. In reference to new technologies he states, "These changes, exactly because they are fundamental, threaten all the vested interests and military 'rice bowls,' from resource allocation, to roles and missions, to the very nature of command and how control is exercised;" Gene H. McCall, Chairman USAF Scientific Advisory Board, presentation to the ***2025*** Study Group, Maxwell AFB, Ala., 6 September 1995. Dr McCall stated in his presentation, "Most revolutionary ideas will be opposed by a majority of decision makers."

17. Jeffrey McKitrick et al., "The Revolution in Military Affairs," in Barry R. Schnieder and Lawrence E. Grinter, eds., *Battlefield of the Future: 21st Century Warfare Issues* (Maxwell AFB, Ala.: Air University Press, September 1995), 71–75; and Andrew F. Krepinevich, Jr., "The Military Technical Revolution: A Preliminary Assessment," in *War Theory Course Book*, vol. 3 (Maxwell AFB, Ala., Air Command and Staff College, September 1995), 163.

18. Gene H. McCall, chairman USAF Scientific Advisory Board, presentation to the ***2025*** Study Group, Maxwell AFB, Ala., 6 September 1995. Dr McCall stated in his presentation, "Early applications of revolutionary concepts should not be required to be complete and final weapon systems."

Chapter 3

Developmental Considerations

The end for which a soldier is recruited, clothed, armed, and trained, the whole object of his sleeping, eating, drinking, and marching is simply that he should fight at the right place and the right time.

—Carl von Clausewitz
On War

Clausewitz's statement of the supremacy of purpose for all that we do in the military applies as much today as it did centuries ago. In his day, military leaders concerned themselves with tailoring, building, and sustaining their forces to "fight at the right place and the right time" with the purpose of winning wars. Today, our leaders are faced with a similar challenge. In our increasingly technological age, military leaders are challenged to develop weapon systems that enable our forces to determine the "right place" and move people, equipment, and supplies to be able to fight at the "right time."

Unmanned aerial vehicles offer military leaders the ability to use *Global Awareness* to more accurately apply *Global Reach* and *Global Power* when and where needed. For years, UAVs have had the capability to push beyond the realm of observation, reconnaissance, and surveillance, and assume traditional tasks normally assigned to manned weapon systems. However, several factors influenced decisions that favored manned aircraft development at the expense of UAVs. A 1981 Government Accounting Office report "alleged inefficient management in the Pentagon in failing to field new [UAV] vehicles. The GAO noted several explanations for the inertia: many people are unfamiliar with the technology, unmanned air vehicles are unexciting compared to manned vehicles, the limited defense budget, and user reluctance—the pro-pilot bias."[1]

Whether one accepts this assessment or not, there have been limited advancements in military UAV development, but not without prompting from external sources. Since 1981, the US Department of Defense has expended a much greater effort in developing, producing, and employing UAVs in the reconnaissance role. In fact, UAVs proved to be a viable force multiplier in the coalition military efforts in the 1991 Gulf War.[2] However, some of those problems identified by the 1981 GAO report continue to exist today and, without additional UAV research and education, may severely limit future development of UAV military potential.

Moreover, the "jump" from using UAVs in nonlethal reconnaissance roles to lethal offensive operations is a dramatic change, adding another consideration to deal with—public accountability. It is likely the American public and international community will demand assurances that unmanned UAVs perform at least as safely as manned aircraft. This requirement must be considered in designing, developing, and employing any lethal UAVs.

This section analyzes this accountability issue and two other considerations: (1) an alleged pro-pilot bias that favors development and employment of manned aircraft over UAVs and; (2) a reduced budget that forces choosing space-based or air-breathing systems in a zero sum battle for military budget dollars.

Pro-Pilot Bias

Under the many challenges of their rapidly changing environment, the Air Force leadership may have become more focused on the preservation of flying and fliers than on the mission of the institution.

—Carl A. Builder
The Icarus Syndrome

Nearly every research effort conducted on UAV development in the last 10 years has either referenced or implied the existence of a "pro-pilot bias." None of those studies, however, defines what constitutes that bias, except in one case where it is described as a "user reluctance."[3] Yet authors state or imply that this bias has been responsible for delaying or undermining efforts in developing and employing operational UAVs since their inception. In the future, to ensure optimization of combat UAVs, underlying concerns must be identified, validated, and dealt with as hurdles to be overcome, not biases.

There are three identifiable concerns that will be analyzed concerning "pro-pilot bias" and its effects on UAV development. First, there is a skepticism that current UAV technology provides the reliability, flexibility, and adaptability of a piloted aircraft.[4] Basically, this perception implies that UAVs are incapable of performing the mission as well as equivalent manned aircraft since they are unable to respond to the combat environment's dynamic changes. This incorrectly assumes all UAVs operate autonomously as do cruise and ballistic missiles. These latter systems do lack flexibility and adaptability, and only do what they are programmed to do. Other UAVs, like the Predator, are remotely piloted vehicles, and are as flexible and adaptable as the operator flying them. The operator's ability to respond to the environment is dependent on external sensors to "see" and "hear" and on control links to provide inputs to and receive feedback from the UAV. Future UAVs using artificial intelligence will respond to stimuli in much the same way as a human, but will only be as flexible and adaptable as programmed constraints and sensor fusion capabilities allow.

In 2025, technology will enable near-real-time, sensor-shooter-sensor-assessor processes to occur in manned and unmanned aircraft operations. The question is not whether either of these systems is flexible and adaptive but whether it is more prudent to have a human fly an aircraft into a hostile or politically sensitive environment, or have an operator "fly" a UAV from the security of a secure site.

Second, there is a perception that UAVs capable of performing traditional manned aircraft missions are a threat to the Air Force as an institution. This perception is deeply rooted in the Air Force's struggle with its own identity, a struggle lasting since the early Army Air Corps days. Carl Builder, in *The Icarus Syndrome*, describes how the Air Force sacrificed airpower theory ("the end") in exchange for the airplane's salvation ("the means") when challenged by arguably more capable "means."[5] Like the intercontinental ballistic missile (ICBM) and cruise missile, the Air Force has struggled against the development of UAVs only to accommodate it when faced with other services' infringement on traditional Air Force missions. Like the ICBM and cruise missiles before it, the UAV has been assigned a support role, primarily in reconnaissance. The problem, according to Builder, is that the Air Force, when faced with challenges to the "flying machine," tends to accommodate new systems instead of adapting doctrine to tie the new "means" to its mission and underlying airpower theory.[6] Thus, Builder asserts the Air Force has been myopic, seeing the "mission" of the Air Force in terms of airplanes, and therefore any system other than an airplane is relegated to mission support, or deemed a threat to the Air Force institution and dismissed. Ironically, the UAV is following the same development path that the airplane took over 50 years ago when the Army culture relegated it to a reconnaissance and mission support role.

Finally, there is a concern among the Air Force's pilot community that UAVs pose a threat to their jobs and, ultimately, their future Air Force roles.[7] There is a perception that UAVs will replace the need for pilots to employ aerospacepower, and closely tied to this belief is the resultant threat to the power base and leadership role pilots have held in the Air Force since its birth. It is easy to rationalize an Air Force founded on flying airplanes led by those who fly them. For years, those who protected the preeminence of the airplane also protected the leadership of the pilots and operators, sometimes at the expense of the institution's well being.[8] If it is right for pilots to lead a "fly, fight, and win" Air Force, then would it be equally right for pilots to step down when the airplane is replaced by cruise missiles, space-based platforms, and UAVs? Pilots, who have held the leadership reins of the Air Force for more than 50 years, are now faced with being replaced with specialists and technologists. This threat and the reaction of today's pilot-laden Air Force leadership will play a major role in determining the UAV's development between now and 2025.

Budget Competition—Space-Based, Air Breather, or Both

Space warfare will likely become its own warfare area only when there is need to conduct military operations in space to obtain solely space-related goals (not missions that are conducted to support earth-based operations).

—Jeffrey McKitrick
The Revolution in Military Affairs

The Air Force is looking to both space and the inner atmosphere for ways to meet future war-fighting requirements. At the same time, budget constraints are forcing the Air Force to be selective in determining which system(s) will receive increasingly dwindling dollars. In the past, UAVs lost similar competitions to manned aircraft in the Air Force's constant attempt to modernize its manned aircraft. Future competitions will still face manned aircraft concerns, but the competition will also be between the UAV and an equivalent space-based platform. This section does not provide a thorough comparative analysis of space-based systems and the StrikeStar. It does provide those who will make the decisions that fund one or both of these systems with (1) an understanding that a competition exists between space-based systems and a StrikeStar concept; (2) some considerations to be used in making those decisions; and (3) recommendations for using the StrikeStar in conjunction with a bolstered space-based system.

Several organizations associated with the Department of Defense's research and development circle are developing space-based systems that can deliver precision lethal and nonlethal force against ground-based targets. Like StrikeStar, these systems have the capability to project power to any point on the earth and do so with a minimal sensor-to-shooter time delay. As orbiting systems, these systems provide decision makers a near continuous coverage of all global "hot spots." In many respects, these systems parallel capabilities provided by a gravity-bound StrikeStar.

Unlike StrikeStar, space-based systems are expensive in research and development, and the space environment provides operational challenges. The budget dollars do not exist now and likely will not exist in the future to fund the simultaneous development of space-based and StrikeStar UAV systems. But more important than lack of money is the waste inherent in simultaneously developing systems that duplicate each other's capabilities without adding any appreciable value.[9] For years, the Navy and Air Force have done just this by developing very similar frontline fighters. Today, the services and Congress understand that this practice results in great waste and that they can reduce that waste by comparing space-based attack system and UAV development now and determining

which strategy will best provide needed capabilities by 2025.

Decision makers must compare space-based and air-breathing systems and determine which will receive development funding. They must consider the capabilities, limitations, and implications of both systems and form a conclusion as to which system or combination of systems provides the needed war fighting capability in 2025. Probably the greatest limitations of space-based systems are the costs associated with transporting the vehicle from the surface to earth's orbit, maintaining it (in orbit or on return), and then transporting it back to the surface. Another significant space-based system limitation is the criticality of the vehicle(s) position or orbit. Space-based systems cannot currently loiter over a target area since orbital mechanics require constant movement around the earth. Therefore, a space-based system needs multiple vehicles to provide constant coverage as well as the ability to position a vehicle when and where needed.

Decision makers must also consider the sociopolitical implications of militarizing space. Some argue control of space is analogous to control of air and that this new frontier should be approached in the same manner the military approached airpower.[10] But this new frontier is inherently different from the skies overlying the earth's nations, and space cannot be divided up in segments as the international community has done with airspace. In fact, space is rapidly being established as an international domain for commercial interests owned by a combination of nation-states and corporate conglomerates. Establishing space dominance will be costly and threatening to an increasingly interdependent international community. Placing an offensive capable platform in space that continuously holds any nation or group of individuals at risk will undoubtedly be perceived as a direct threat to friendly or enemy nations.

A less threatening alternative for space is the enhancement of current military capabilities in the areas of reconnaissance, navigation, and communications with concurrent development of space-to-space weapon systems designed to protect our space-based assets. Also, challenges associated with projecting lethal and nonlethal force from space-to-surface targets may be too difficult and costly when compared with inner-atmosphere systems with similar capabilities. Offensive and defensive space-based systems are essential, but primarily for missions that support space requirements and not for direct attack against inner-atmosphere targets.

Probably the greatest limitation of air-breathing UAVs compared to an equivalent space-based system is the time delay required to mobilize and deploy it to a theater of operations. StrikeStar is designed to deploy-loiter-strike-loiter-redeploy from either CONUS or a forward base, but due to fuel limitations, the time required to deploy and redeploy are contingent on the distance to the area of operations, and this also directly affects available loiter time. Because StrikeStar cannot stay airborne indefinitely, it may require advanced warning times or an increased number of vehicles to provide continuous coverage of the operations area.

Because of high costs to develop, operate, and maintain space-based systems that might deliver lethal force on the earth's surface, the armed forces should tailor development of space-based platforms to lethal missions that focus on space-only missions and nonlethal missions supporting earth-bound lethal weapon systems. StrikeStar and a new generation of UAVs capable of delivering lethal and nonlethal force provide a low cost, highly mobile platform that will enable the US military and civilian authorities to project power to any point on the globe in minimal time and hold an area at risk for days at a time. StrikeStar is not a threat to space, but simply provides an effective capability that when directed by air, land-based, or space-based command and control can reach out and touch enemies threatening our national interests throughout the world.

Public Accountability

War is a human endeavor, fought by men and women of courage. The machines, the technology help; but it is the individual's skill and courage that makes the crucial difference.

—Gen Gordon R. Sullivan
Army Focus 1994: Force XXI

The public will demand accountability for lethal UAVs and their operations, and StrikeStar's lethal potential requires assurances that prevent inadvertent or unintentional death and destruction to both friendly and enemy troops.

Imposed Limitations

Restrictions must be placed on lethal UAVs because of the potential consequences of an accident or malfunction. Recent history has proven that the American public and the international community hold individuals and organizations accountable for decisions to use force. The downing of two US helicopters supporting Operation Provide Comfort in northern Iraq and the subsequent loss of 24 lives provide a vivid example of how the public will react to lethal force "accidents" or "mistakes." Today, accident- or mistake-justifications do not warrant death or destruction.

Even in war, use of legitimate lethal force will be questioned. Society has become more sensitive to death and destruction as the information age provides real-time, world-event reporting. Television presents images and political commentary, probing and demanding justification for using lethal force. The intent of those inquiries is to determine accountability when events result in questionable death or destruction. Also, technology has legitimized precision warfare, and "criminalized" collateral death and destruction resulting from the use of lethal force. The perception exists among the press and public that it is now possible to prevent nearly all types of accidents and mistakes and only shoot the "bad guy."

These perceptions place limits on using any system that could deliver lethal force. StrikeStar falls within this category and it is imperative that accountability be built into the system design and concept of operations.

But how do we create accountability? First, a human must be involved in the processes that result in lethal force delivery. Second, redundancy must be designed into the system to ensure a person can exercise control from outside the cockpit. Third, the system must be responsive to the dynamic environment in which it will operate. Finally, reliability must be designed into every StrikeStar system and subsystem to minimize the possibility of inadvertent or unintentional use of lethal force. In total, these measures place a human in the decision-making position when employing lethal force. Thus, when an accident or mistake occurs, a person, not a machine, is responsible and accountable. For claiming a system failure, or "it just blew," will not suffice.

Man-in-the-Loop

Accountability is not well suited for anything other than a person. When an aircraft crashes, the mishap board's task is to find causal reasons for the crash. Even when it becomes apparent a broken or malfunctioning part contributed to the crash, the board probes the processes involved in its production, installation, and even documentation. Since processes are created and normally managed by people, accountability is normally given to a person.

So humans must be involved in the decisions that could result in intentional or unintentional death and destruction. But human input is not required in all phases of flight and there are various ways to keep a person in the loop without putting a pilot in a cockpit. However, because of the potential consequences of mistakes or accidents, human input must be involved in target selection and weapons delivery decisions.

The man in the loop can be attained through nearly all of the potential controlling mechanisms available now and forecast into the future. UAV control mechanisms included manned, remotely piloted, semi-autonomous (combined RPV and programmed),

autonomous (programmed/ drone), and fully adaptive (artificial intelligence). StrikeStar control mechanisms allow for inflight human input, but an autonomous system preprogrammed to hit a prelaunch designated target or target area with minimum human intervention and not normally changed in flight could be used. Also, a fully adaptive UAV using artificial intelligence could be programmed to mimic the decisions a pilot would make in reacting to environmental changes.

Although it can be suited to some missions, a lethal UAV with autonomous or fully adaptive controls pose significant accountability problems. First, decisions to target and strike are made without regard to a rapidly changing environment. For example, a Tomahawk land attack missile (TLAM) might hit a command post even though, in the time since it was launched, a school bus full of children stopped nearby. An autonomous system has no way of knowing current or real-time information that may affect the decision to target and strike. Second, autonomous UAVs cannot react to internal malfunctions that might affect their ability to perform their prescribed missions. A preprogrammed UAV told to deliver its weapon will do so even though its targeting system has malfunctioned and the result is a bomb dropped with unknown accuracy. The net effect in both situations is inadvertent or unintentional delivery of lethal force and an accountability question.

Obviously, 100 percent reliability is not guaranteed even with a human in the decision-making process, but 100 percent accountability must be attempted. The further a person gets away from lethal force accountability, the easier the "fire" decision is and the greater the probability that the wrong target will be hit. As a result of this tendency and the severity of the consequences, our air-to-air rules of engagement favor visual identification over system interrogation and identification. A person must be kept in the loop when using UAVs to deliver lethal force.

Redundancy

To keep man in the loop and maintain this accountability, we must ensure the control links are sufficiently redundant. There are two potential centers of gravity that, if intentionally or unintentionally targeted, would remove or degrade the man in the loop. First, the control links are susceptible to meaconing, intrusion, jamming, and interference (MIJI). In this case, the "lines" between the UAV and the controller are severed or degraded to a point where the UAV is basically autonomous. Second, the controller or the controllers' C^4I facilities are also susceptible to physical destruction, equipment malfunctions, and situational dis/misorientation. In this case, the source of the signals or an intermediary relay (e.g., satellite) would be physically incapable of sending or transmitting control signals to the UAV. In either case, the UAV is without a man in the loop.

Controller backup systems need to be able to deal with contingencies that could threaten the UAV's ability to accurately hit its designated target. The StrikeStar should have triple redundancy built into the controlling system utilizing a ground source, airborne source, and an autonomous backup mode. Should the UAV detect an interruption of controller signals, it could enter an autonomous mode and attempt to reconnect to its primary controller source. If unable to reconnect, it could search for a predesignated secondary controller input and establish contact with the backup controller. The final option available if the UAV can not regain controller input would be to follow the last known program or abort, depending on its prelaunch abort configuration.

Responsiveness

The StrikeStar system must be responsive to a dynamic environment and design must include flexible C^4I systems, C^2 operations, and UAV guidance and fire control systems. It is imperative that a lethal UAV be able to assess its environment and adapt to it accordingly. This requires real-time data

and assessment, high-speed data transmission capability, flexible C^2 procedures, reliable controller capability, and a real-time reprogramming capability.

An advantage of a manned aircraft is that the pilot can make the last-second decision to deliver the weapon, abort the delivery, or change targets as the situation dictates. At the last-second, a pilot can detect an unknown threat preventing him or her from reaching the target, and has the ability to change targets when the original target has moved. Simply, a pilot has the ability to assess and react to an environment characterized by fog and friction.

Lethal UAVs (and/or their controllers) must have the same ability to adapt to an unanticipated or dynamic environment. They must be able to discern the environment, consider the threat (in cost-benefit terms), confirm the intended target, and have the ability to deliver, abort, or change to a new target. The consequences of not having this ability relegates the UAV to an autonomous system and raises accountability questions in the event of an unintentional or inadvertent delivery. Real-time information and control is essential to protecting our accountability in lethal UAVs.

Reliability

The UAV and its many subsystems must have a high operational reliability rate to prevent accidental destruction and collateral damage. Unlike nonlethal UAVs, unmanned systems carrying lethal munitions could have destructive effects in an accident or systems-related malfunction. Lethal UAVs must have a higher reliability confidence level than a manned system because UAV system malfunction effects could prove to be more disastrous.

Summary

StrikeStar as well as other systems that deliver lethal force will be scrutinized when accidents occur, especially those that result in unintentional or inadvertent loss of life or treasure. The public will demand accountability for lethal UAVs and their operations. Therefore design, development, and employment of the StrikeStar must integrate the concept of accountability. Humans must remain in the command and control loop, and the internal and external systems and links must be robust enough to keep that loop intact. The sociopolitical implications are too high to ignore these facts.

Conclusion

Although the StrikeStar concept can be proven to meet an operational need, is technically feasible, and fits into a sound concept of operations, it may go the way of previous UAV concepts. Forces exist today that could slow or deny the development of a lethal UAV for use in 2025. Most prevalent are the historical bias for manned aircraft over UAVs, budget competition between space development and the UAV programs, and, finally, the public pressure that increasingly requires accountability when things go wrong. These forces need to be understood and met openly as we start developing a StrikeStar.

Notes

1. David H. Cookerly, *Unmanned Vehicles to Support the Tactical War* (Maxwell AFB, Ala.: Air University Press, May 1988), 25.
2. Lt Col Dana A. Longino, *Role of Unmanned Aerial Vehicles in Future Armed Conflict Scenarios* (Maxwell AFB, Ala.: Air University Press, December 1994), 9.
3. Ibid., 25.
4. Ibid., 28.
5. Carl H. Builder, *The Icarus Syndrome* (New Brunswick, N.J., 1994), 200.
6. Ibid., 205.
7. Longino, 13.
8. Builder, 200.
9. Jeffrey McKitrick et al., "The Revolution in Military Affairs," in Barry Schnieder and Lawrence E. Grinter, eds., *Battlefield of the Future; 21st Century Warfare Issues* (Maxwell AFB, Ala.: Air University Press, September 1995), 78.
10. McKitrick, 89.

Chapter 4

StrikeStar Technology

The system was so swift that human beings simply could not handle the target volume without extensive automated support, and the system was designed to fight on full automatic, relying on its human masters for key decisions, for overall guidance, for setting or revising priorities, and for defining operational parameters. Technically, this most potent warfare machine ever built had the capability to carry on the fight indefinitely.

—Ralph Peters
The War in 2020

The war machine described above is fiction, but the technology is within our grasp to make it a reality. In the past, UAV systems have been plagued with reliability problems or by design flaws (see appendix A).[1] Recently, the joint tactical UAV Hunter was canceled due to continuing reliability problems.[2] Current efforts are producing mature technology that improves overall reliability and functionality. The first DOD UAV master plan was produced to consolidate requirements and integrate efforts across all DOD agencies.[3] The Global Hawk and DarkStar UAVs are excellent examples of how quickly UAV systems technology is advancing. Table 1 provides a summary of US UAV characteristics from a system capabilities perspective.

This family of UAVs capitalized on past accomplishments and started the evolutionary process of adapting technologies proven in manned aircraft to UAV platforms. Other countries are also involved in UAV technology and have recognized the roles UAV will have on future battlefields (see appendix B).[4] Trends indicate that a wide range of anticipated technologies will support the StrikeStar concept and provide platform robusting. Some include

Table 1
US UAVs, System Characteristics

Characteristic	Maneuver UAV	Interim Joint Tactical Pioneer	Joint Tactical Hunter	MAE Predator	CHAE UAV Global Hawk Tier II Plus	LOHAE UAV DarkStar Tier III Minus
Max Altitude (ft)	13,000	15,000	25,000	25,000	>65,000	45,000
Endurance (hrs)	3	5	12	>24	>24	>8
Rad. action (nm)	27	100	>108	500	3,000	>500
Max Speed (kts)	TDB	110	106	129	>345	>250
Cruise Speed	<90	65	>90	110	345	>250
Loiter Speed	60–75	65	<90	70–75	340	>250
Payload Wgt (lbs)	50	100	196	450	2,140	1,287
Max Wgt	200	429	1,700	1,873	24,000	8,600
Navigation	GPS	GPS	GPS	GPS/INS	GPS/INS	GPS/INS

Source: *Unmanned Aerial Vehicles*, Defense Airborne Reconnaissance Office Annual Report (Washington, D.C., August 1995).

1. airframe technology
2. avionics systems
3. propulsion technology
4. weapon systems
5. communications systems
6. mission control equipment
7. launch and recovery equipment

Sensor technologies are not critical to the construction and design of StrikeStar, but are critical to its operation. We expect reconnaissance efforts for both manned and unmanned aircraft and space platforms will continue to advance. StrikeStar will rely on other platforms for target identification, but could have the capacity to carry reconnaissance sensors using modular payload approaches. This concept does not advocate combining expensive reconnaissance sensors on the same platform carrying a lethal payload, since separating sensors from the weapon platform lowers costs and lessens the risk of sensor loss.

The technologies noted above have to support the system characteristics shown in table 2 to ascertain current capabilities and identify enabling technologies that support the StrikeStar concept. Our baseline for the system characteristics is based on a melding of the Global Hawk and DarkStar performance attributes. The range and loiter improvements allow us to overcome the basing and response constraints mentioned in chapter 2. Adding stealth characteristics to a Global Hawk-size UAV reduces vulnerability and allows covert operation. Improved payload capacity allows the ability to carry both more and varied weapons. The envisioned altitude improvements allow for airspace deconfliction, self defense, and weapon range and dispersion performance.

Airframe Technology

Past UAV systems have used both fixed and rotary wing configuration. Rotary wing systems overcome many of the problems associated with launch and recovery, and optimize sensory payload operations. The Sikorsky Cypher provides a recent, successful demonstration of rotary wing technology.[5] Unfortunately, most rotary wing systems have limited range and endurance capabilities. Most UAVs fall into the fixed wing category including all those currently in service worldwide.[6]

Table 2
StrikeStar System Characteristics

Characteristic	StrikeStar
Wingspan (ft)	105
Max Altitude (ft)	>80,000
Endurance (hrs)	>40
Rad. action (nm)	3,700 w/24 hr loiter
Max Speed (kts)	>400
Cruise Speed (kts)	400
Loiter Speed (kts)	400
Payload Wgt (lbs)	4,000
Max Wgt (lbs)	24,000
Navigation	GPS/INS

Typical low performance fixed wing systems employ rear-mounted pusher propellers, such as the Predator UAV, or tractor propellers. Systems have single or twin tail booms and rely on their relatively small radar cross section and low noise generation to avoid detection. The Hunter platform shown in figure 4-1 is a prime example of a UAV using push-pull engine technology on a twin boom airframe.

Designs to date have focused on using existing manned airframe components or designs to minimize cost or produce operational platforms quickly. These systems support moderate payloads over various ranges despite known aerodynamic deficiencies. The advent of the DarkStar platform demonstrates an innovative approach to improve both aerodynamic efficiency, payload support, and operational radius.[7] DarkStar's use of a jet engine coupled with a composite flying wing structure will improve aerodynamic efficiencies and significantly decrease the radar cross section.

As currently designed, the DarkStar UAV consists of an internal payload bay capable

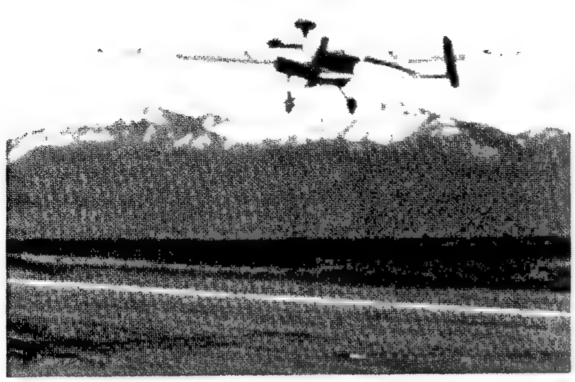

Figure 4-1. Twin-Boom Hunter UAV

of supporting a sensor payload that can be swapped in the field. The current payload capacity and platform configuration does not allow DarkStar to function as an efficient strike platform. Skunk Works designers are continuing evolutionary improvements on the DarkStar platform. Their conceptual design in figure 4-2 provides a look at a twin engine platform capable of increased range, speed, and payload capacity that has the potential to function as a UAV strike platform. This design could serve as the basis for future StrikeStar developments.

StrikeStar designers could capitalize on DarkStar payload swapping techniques as well as internal weapon carriage technology used for the F-117 and F-22 airframes. Future generations of StrikeStar airframes would rely on larger payload bays and wider use of composite materials to improve payload capacity and stealthiness without increasing total weight. We anticipate that stealth technologies will mature to the point that cloaking or masking devices could be used to prevent detection or the employment of effective countermeasures.[8]

Onboard Control Systems

The avionics system would support two modes of platform operation: command-directed and autonomous. In command-directed operation, the StrikeStar operator would transmit the desired strike mission way points, cruising speed, and flight altitude to the StrikeStar flight control system to perform normal flight operations. Preprogrammed operations would be possible if all known way points were entered prior to a mission. Default preprogrammed operations would commence if uplink communications were lost and not recovered within a user-selectable time frame. Defaults could include entering preplanned holding patterns or initiating preplanned egress maneuvers as determined by the onboard Virtual Pilot system described later.

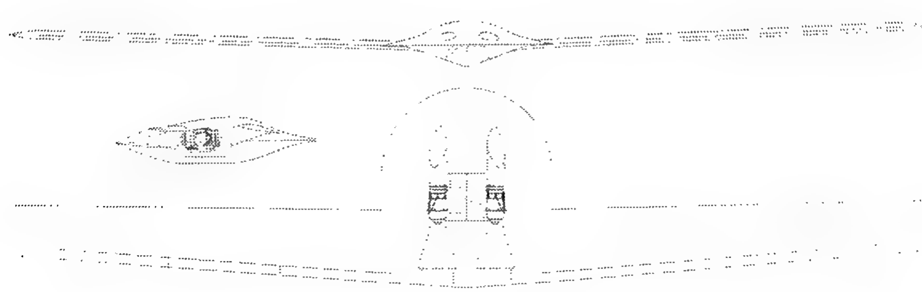

Figure 4-2. Notional StrikeStar

The avionics system would be based on concepts embodied in the Pave Pace integrated avionics architecture. Pave Pace is a concept that uses a family of modular digital building blocks to produce tailorable avionics packages. Using this approach on the StrikeStar would allow for future growth and allows the UAV avionics to mirror manned platform components without adding additional avionics maintenance requirements. A notional avionics system, based on the Pave Pace integrated avionics architecture is shown in figure 4-3.

The StrikeStar flight control system would rely on an integrated system consisting of a global positioning system (GPS) receiver, an inertial navigation system (INS), autopilot, and various sensing and control functions. StrikeStar navigation would rely on GPS precision "P" code data. Eventually, as potential enemies develop GPS jamming capabilities to prevent GPS use in target areas, an INS could provide redundancy and allow limited autonomous operation in the event GPS countermeasures are encountered. Other UAVs could also be used to broadcast high power, synchronous broadband satellite signals over target areas to counter GPS countermeasures.[9]

GPS location data could be transmitted to the control station at all times except in autonomous or preprogrammed operation. Components produced in the Tri-Service Embedded GPS/Inertial Navigation System (EGI) Program, which integrates GPS into the fighter cockpit for better navigation and weapon guidance, could be adapted for use in StrikeStar.[10] In addition to GPS data, StrikeStar would transmit altitude, airspeed, attitude, and direction to control station operators as requested.

The Virtual Pilot provides StrikeStar with a computational capability far exceeding current airborne central computer processing capabilities. Virtual Pilot would consist of an artificial intelligence engine relying on a massively parallel optical processing array to perform a wide range of pilot functions during all operational modes. In addition, the Virtual Pilot could perform self-diagnostic functions during all phases, flight operation phases, and maintenance checks. An antfratricide system would reside in the Virtual Pilot to ensure that combat identification of friendly forces is

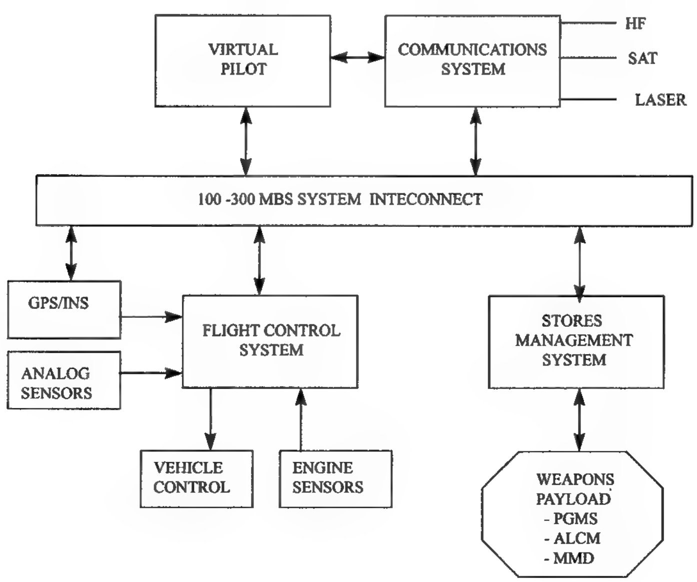

Figure 4-3. StrikeStar Notional Avionics

accomplished before weapon release. This would provide an additional fail-safe to any battlefield awareness systems present in the target area and allow limited extension of a battlefield combat identification to future allies operating with US forces. StrikeStar would also be capable of interrogating and classifying identification friend or foe (IFF) transponder-equipped platforms to facilitate use of that data in air-to-air engagements and identify potential airborne threats.

Propulsion System

Many current UAV systems are based on inefficient, propeller-driven airframes powered by internal combustion engines, relying on highly volatile aviation gasoline, which causes military forces significant safety and logistics issues. Propeller improvements are progressing, but the desire for stealthy platforms steers many designers away from these systems with the exception of the Predator. Gas turbine engines have been demonstrated for rotary wing applications and the use of jet engines has been widely demonstrated and proven highly effective in combat operations.[11] Significant research has been conducted on electrically powered platforms that rely on expendable and rechargeable batteries. Recently, fuel cell application research increased, as evidenced by demonstrations of the solar rechargeable Pathfinder.[12] Unfortunately battery and fuel cell systems exhibit low power and energy densities relative to hydrocarbon fuels. For that reason, internal combustion engines will continue to be the mainstay for less sophisticated UAV propulsion systems.

Jet engine design is a trade-off between airflow and fuel to maximize performance. Engine designers either enlarge the size of engine intake to increase airflow or provide more fuel to the jet engine combustion chambers to produce the desired propulsion characteristics. Since most jet engines rely on conventional fuels, designers increased intake size to maximize fuel efficiency and improve range and endurance. However, increasing UAV intake size is not desirable since this impacts the stealth characteristics and overall aerodynamic efficiencies of small airframes. Exotic or alternative fuels hold much promise for powering future aircraft and extensive research has been conducted on potential new aircraft fuels. Table 3 provides some potential aircraft fuel characteristics.

Exotic fuels have been used for manned platforms in the past, but only in isolated cases because of the risks associated with them. Risk to man is minimized on UAV platforms except during launch and recovery cycles, and while storage of exotic fuels remains a concern, storage technology is improving. Still, exotic fuels represent a

Table 3

Fuel Characteristics

Fuel	Btu/lb	Btu/cu ft	lbs/cu ft	Btu/lb of fuel
JP	18,590	940,000	50.5	0.47
Hydrogen	51,500	222,000	4.3	3.20
Methane	21,500	570,000	26.5	0.49
Propane	19,940	720,000	36.1	0.65
Methanol	8,640	426,000	49.4	0.60
Boron	30,000	1,188,000	39.6	0.57
JP from coal	18,830	996,000	53.0	0.47

Source: Senate, *Hearings before the Subcommittee on Aerospace Technology and National Needs of the Committee on Aeronautical and Space Sciences,* 94th Congress, 2d sess., 27–28 September 1976.

viable option for improving enthalpy on UAV platforms. Hydrogen-based fuels provide significant increases in energy density over conventional hydrocarbon fuels, and such fuels could be widely employed in UAVs by 2025 if current research advances continue and a nationwide manufacturing and distribution network emerges.

Weapon Systems

Weapons with current, precision-guided-munitions characteristics, new nonlethal weapons, and directed-energy weapons could provide StrikeStar with the capability to strike at all levels of conflict from military operations other than war to full-scale war. The key to producing a StrikeStar that can hold the enemy at risk is to deploy weapon systems that have all-weather and extremely precise aimpoint capabilities.

Precision-guided munitions are widely accepted as demonstrated during the Persian Gulf War. The family of launch and leave low-level guided bombs (LLLGB), Maverick, and homing antiradiation missiles (HARM) all represent current weapons that could be integrated into a UAV strike platform. Unfortunately, these weapons lack range and poor weather capability. New all-weather seekers are needed to provide desired battlefield dominance. New studies to produce long-range hypersonic PGMs are also underway, which if employed on a StrikeStar could significantly extend the weapon employment zone.[13] Efforts underway on the Low-Cost, Anti-Armor Submonition Program (LOCASS) should produce weapons technology that not only discriminates against ground targets, but operates in adverse weather conditions.[14]

Stores management systems (SMS) used in modern attack aircraft could be integrated into UAV avionics packages to provide required weapon control and release functions. Tight coupling between sensor platforms, the Virtual Pilot and SMS could allow for autonomous weapon selection, arming, and release without operator intervention under certain scenarios. Unfortunately, the weight and large size of current PGMs and limited functionality of current SMS suites could limit conventional weapon employment.

Recent developments on an enhanced 1,000-pound warhead proved that blast performance of 2,000-pound MK-84 is obtainable.[15] Improved explosives are an enabling technology that would reduce weapon size without decreasing blast performance. Guidance and warhead improvements envisioned in the Miniaturized Munitions Technology Demonstration (MMTD) effort could produce a new class of conventional weapons. The MMTD goal is to produce a 250-pound class munition effective against a majority of hardened targets previously vulnerable only to 2,000-pound class munitions.[16] A differential GPS/INS system will be integral to the MMTD munition to provide precision guidance, and smart fusing techniques will aid in producing a high probability of target kill. The kinetic energy gained by releasing these weapons at maximum StrikeStar altitudes would also help improve explosive yield. Improving bomb accuracy, focusing on lethality, and providing an all-weather capability are all technology goals which, when coupled with a StrikeStar platform, could produce a potent strike platform. MMTD advances would significantly improve weapons loading on StrikeStar. Unfortunately, conventional explosives technology has the limitation that once all weapons are expended, the UAV must return to base for replenishment. However, StrikeStar directed energy weapons would allow more strikes and reduce replenishment needs.

Directed-energy weapon (DEW) technology is undergoing rapid advances as demonstrated on the Airborne Laser program. The goal to produce a laser capable of 200 firings at a cost of less than $1,000 per shot is realizable in the near future.[17] The ability for rapid targeting, tracking, and firing of a UAV-mounted DEW could deny enemy forces the ability to maneuver on the ground and in the air. If initiated now, expanded

research efforts could produce a smaller, more lethal, directed-energy weapon suitable for a StrikeStar platform in 2025.

Capabilities in present air-to-air weapons provide a level of autonomous operations, which if employed on StrikeStar could revolutionize offensive and defensive counter air operations. A StrikeStar loaded with both air-to-ground and air-to-air missiles could be capable of simultaneous strike and self-defense. Additional survivability could be provided by using towed decoys cued by off-board sensors. Advanced medium range air to air missile (AMRAAM) and air intercept missile (AIM-9) weapons are proven technologies already compatible with stores management systems that could be employed on StrikeStar. Internal carriage and weapon release of these missiles from a StrikeStar could rely on experiences gained in the F-22 program. Eventually, a new class of air-to-air missiles that are significantly smaller and more lethal could be developed to allow additional weapon loading.

Nonlethal weapons also present some unique possibilities for use on the Strike-Star. Nonlethal weapons are defined as

> discriminate weapons that are explicitly designed and employed so as to incapacitate personnel or material, while maintaining facilities.[18]

Nonlethal weapons that disorient, temporarily blind, or render hostile forces or equipment impotent, provide alternative means for neutralizing future opponents without increasing the political risk that death and destruction can bring.[19] Employ-ing these weapons from StrikeStar platforms could be used in prehostility stages to demonstrate resolve and the dominant presence of orbiting weapon platforms with instantaneous strike capabilities.

Communications Systems

"What the warrior needs: a fused real-time, true representation of the Warrior's battle space—an ability to order, respond, and coordinate horizontally and vertically to the degree necessary to prosecute his mission in that battle space."[20] To provide continuous battlefield dominance, information dominance is critical for StrikeStar operations. Battlespace awareness as envisioned under the *C⁴I for the Warrior Program* will provide the information infrastructure required for command and control (C²) of the StrikeStar platforms. UAV communications systems function to provide a communications path, or data link, between the platform and the UAV control station, and to provide a path to pass sensor data. The goal of the C⁴ system is to have the head of the pilot in the cockpit, but not his body.[21]

StrikeStar communications would provide a reliable conduit for status information to be passed on a downlink and control data to be passed on the uplink in hostile electronic environments. The uplink and downlink data streams would be common datalinks interoperable with existing C⁴ datalinks to maximize data exchange between sensors, platforms, and their users. Status and control information would be continually transferred between StrikeStar and its controller in all cases except during autonomous operation or implementing preprogrammed flight operations. The datalink would need to be impervious to jamming, or even loss of control, to ensure weapon system integrity. User-selectable, spread spectrum, secure communications in all transmission ranges would provide redundancy, diversity, and low detection and intercept probability. Both beyond line-of-sight and line-of-sight communications methods would be supported to a variety of control stations operating from aerospace, land, and sea platforms.[22]

Command and control of UAVs via satellite links has been demonstrated to be highly reliable.[23] The MILSTAR constellation or its follow-on could serve as the primary C² communications network for StrikeStar platforms. MILSTAR's narrow-beam antennas coupled with broad-band frequency hopping provides isolation from jammers and a very low probability of detection.[24] The Defense

Satellite Communications System (DSCS) constellation and Global High-Frequency Network could provide alternate paths for connectivity and redundancy depending on mission profiles. The vast high-frequency (HF) network provides nearly instantaneous coverage and redundancy under adverse environmental conditions (fig. 4-4).[25] High-frequency can provide commanders with useful, flexible, and responsive communications while reducing the demand on overburdened satellite systems.[26] The continued proliferation of commercial satellite networks may allow StrikeStar platforms to exploit these networks as viable communications paths as long as C^2 integrity of on-board weapons is assured.

StrikeStar would rely on other platforms, like Predator, DarkStar, Global Hawk or ground, airborne, or space reconnaissance, to detect and locate potential targets. The StrikeStar could team with any or a combination of all these assets to produce a lethal hunter-killer team. Once geolocated, the target coordinates would be passed to StrikeStar along with necessary arming and release data to ensure successful weapon launch when operating in command-directed mode. In autonomous mode, StrikeStar would function like current cruise missiles, but allow for in-flight retargeting, mission abort, or restrike capabilities. Communications for cooperative engagements with other reconnaissance platforms require minimum bandwidth between StrikeStar and its control station since the targeting platforms already provide the large bandwidth necessary for sensor payloads.

As with any C^4 system, we anticipate StrikeStar's requirements would grow as mission capabilities and payloads mature. It is possible StrikeStar follow-ons could be required to integrate limited sensing and strike payloads into one platform, thus significantly increasing datalink requirements. In this event, wideband laser datalinks could be used to provide data rates greater than one gigabit per

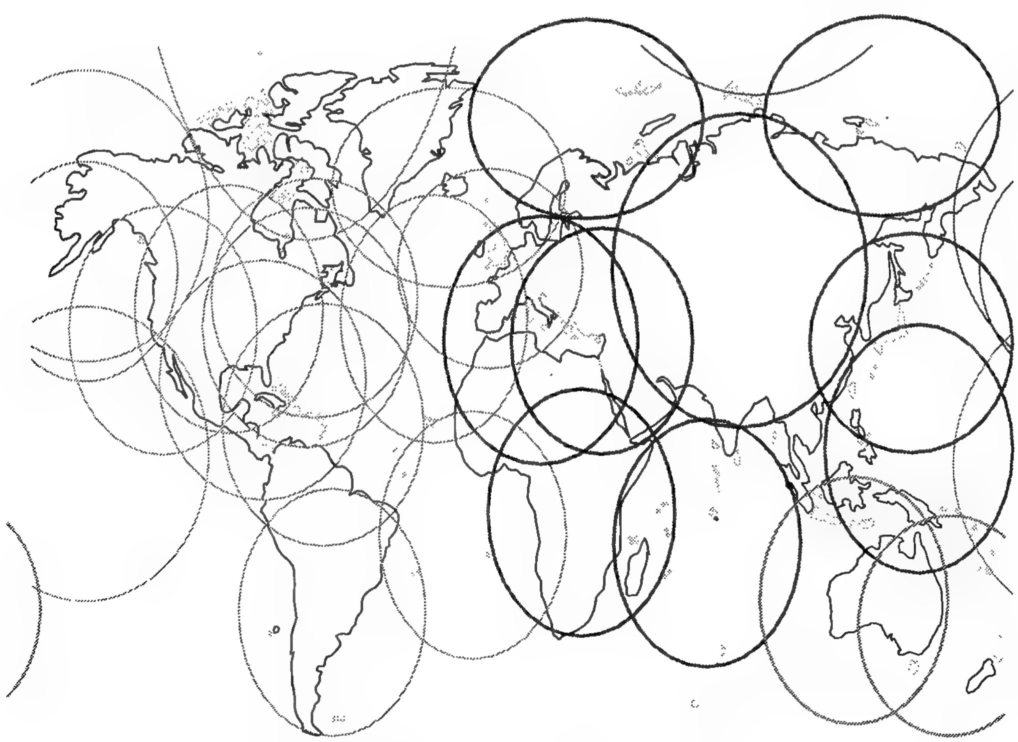

Figure 4-4. Global HF Network Coverage

second.[27] In addition, a modular payload capability could allow StrikeStar platform to carry multimission payloads such as wideband communications relay equipment to provide vital C^4 links to projected forces.[28]

Mission Control Equipment

As mentioned, StrikeStar will be controllable from a multitude of control stations through the common datalink use. Control stations could be based on aerospace, ground, or sea platforms depending on the employment scenario. A control station hierarchy could be implemented depending on the employing force's composition and the number of StrikeStars under control. The StrikeStar C^2 hierarchy and control equipment would allow transfer of operator control to provide C^2 redundancy. Current efforts by DARO have established a common set of standards and design rules for ground stations.[29] This same effort needs to be accomplished for aerospace and sea-based control stations.

Significant efforts to miniaturize the control stations would be needed to allow quick deployment and minimum operator support through all conflict phases. Man-machine interfaces would be optimized to present StrikeStar operators the ability to sense and feel as if they were on the platforms performing the mission. Optimally, StrikeStar control could be accomplished from a wide variety of locations ranging from mobile ground units to existing hardened facilities. The various control stations would be capable of selectively controlling StrikeStars based on apriori knowledge of platform C^2 and identification procedures.

Launch and Recovery Equipment

Launch and recovery are the most difficult UAV operations and are the greatest factors inhibiting wider acceptance.[30] A variety of launch and recovery systems are used worldwide. Launchers range from simple hand launchers to sophisticated rocket-assisted take-off systems (fig. 4-5). Recovery systems range from controlled crash landings to standard runway landings. StrikeStar would launch and recover like manned aircraft, and carrier-based operations could be considered as another viable option to improve loiter times and mission flexibility.

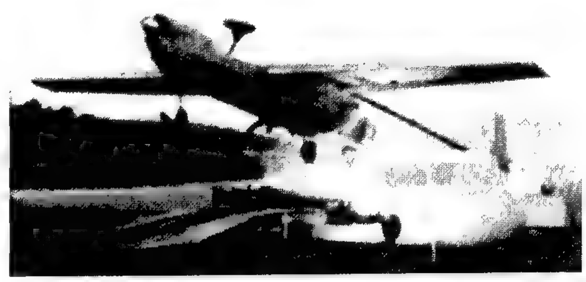

Figure 4-5. Rocket-Assisted Hunter UAV Launch

The goal for StrikeStar launch and recovery would be autonomous launch and recovery via an enhanced landing system (ELS), although it could operate with the current instrument landing system (ILS) and microwave landing system (MLS) equipment under operator control. ILS is prone to multipath propagation and MLS is susceptible to terrain variations and the presence of nearby objects; thus neither would be acceptable for truly autonomous recovery of StrikeStar platforms.[31] The ELS would overcome these deficiencies by using GPS, high resolution ground mapping techniques, and optical sensing to land without operator control.

Technologies to support the StrikeStar do not appear to represent significant challenges. In most cases proven technologies can be expected to evolve to a level that will overcome all hurdles by the year 2025. Determining the doctrinal and operational changes required to integrate a StrikeStar capability presents more significant challenges, considering the

aversion our service has had with UAVs in the past.[32] Technology for StrikeStar is evolutionary where as organizational acceptance and employment will be revolutionary.

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Chapter 5

StrikeStar Concept of Operations

We're getting into UAVs in a big way. We understand they have enormous potential.

—Gen Joseph W. Ralston

The purpose of the StrikeStar concept of operations is to define the operational application of the StrikeStar by highlighting system advantages, defining future roles and missions, and illustrating interrelationships between intelligence, command and control (C^2), the weapon, and the war fighter.

The Dawn of a New Era for Airpower

Historically, America has held expectations for airpower just beyond the limits of available technology, and now a new national expectation is emerging. Today, airpower application is expected to equate to cost-effective, precise, and low-risk victory.[1] These inexorable expectations could be a reality in 2025 because a StrikeStar could hold strategic, operational, and tactical targets at risk with relative immunity to enemy defenses. This platform could operate in high risk or politically sensitive environments, perform its mission, and return to fly and fight again. The StrikeStar would enable the United States military to meet the national expectations and the threats of a changing world.

Underpinning the StrikeStar concept is the platform's ability to deliver increased combat capability with reductions in vulnerability and operating cost. The StrikeStar's 8,000 nautical mile combat radius would have the potential to keep vulnerable logistics and maintenance support far from hostile areas. Also, dramatic savings would be possible in operations, maintenance, personnel, and deployment costs. Logistically the StrikeStar could be handled like a cruise missile—stored in a warehouse until needed and then pulled out for a conflict. The potential savings over conventional aircraft could range from 40 percent to as much as 80 percent.[2] Training could be conducted using computer simulation with actual intelligence, surveillance, and reconnaissance inputs. While potential savings are impressive, the most attractive aspects of this platform and its supporting elements are the capabilities the StrikeStar System could deliver to tomorrow's commanders in chief (CINC):

1. The StrikeStar could be configured to perform a variety of missions as diverse as surveillance to the delivery of precision weapons.

2. Operating altitudes could make it a true all-weather platform capable of remaining on-station regardless of area of operations (AO) weather.

3. Battlespace presence: depending on the weapons carried, a handful of StrikeStars could equate to continuous coverage of the AO.

4. Power projection: StrikeStar operations need not compete for ramp space with other theater assets. The combat radius would normally facilitate operations from coastal Continental United States locations or strategically located staging bases to improve loiter time (fig. 5-1).

5. Such an aircraft could accelerate the CINC's Observe, Orient, Decide, Act loop (OODA Loop) with immediate battle damage assessment (BDA) and restrike capability.

6. The employment concept of operations could shorten the chain of command, simplifying accountability and improving operations security.

7. A StrikeStar could enable a CINC to operate in environments where casualties, prisoners of war, or overt United State military presence are politically unacceptable.

8. A StrikeStar and its supporting systems could be tailored to have utility across the across the spectrum of conflict.

9. A StrikeStar in a combat environment could "buy back" battlespace flexibility.[3]

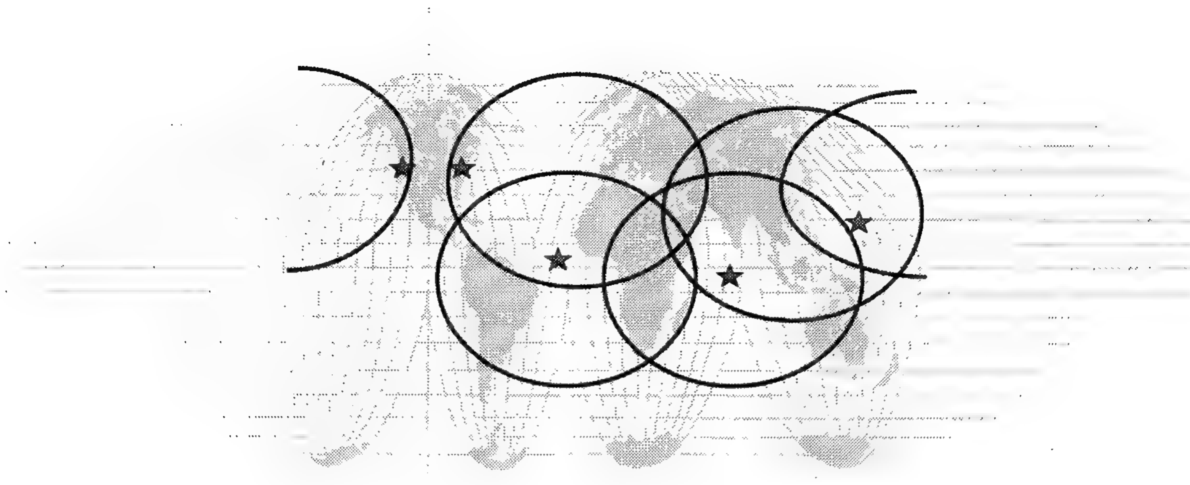

Figure 5-1. StrikeStar Coverage

Roles and Missions

Aerospacepower roles and missions in 2025 are difficult to predict, yet we know they will be tied to the nature of future conflict. Desert Storm has been touted by many as the first modern war and a clear indicator of the nature of future conflict. Others believe that the conflict was not the beginning of a new era in warfare but the end of one, perhaps the last ancient war.[4] In terms of readying aerospace forces for the future, it is imperative we look for discontinuities in the nature of future war as well as commonalties to past conflicts. It is a fact that our future roles and mission will be a reflection of our technological capabilities and most significant centers of gravity as well as those of our enemies.[5] It is safe to say the missions that are the most challenging today will be the core requirements of aerospacepower tomorrow.

The StrikeStar complements the current understanding of air roles and missions and could provide a technological bridge to accomplish future roles and missions. The platform's most natural applications would be in aerospace control and force application roles; however, planned versatility also makes it a force multiplier and a force enhancer.[6] A payload and communications package swap could enable a StrikeStar to perform electronic combat, deception, or reconnaissance missions. A StrikeStar could act as a stand-alone weapons platform or it could multiply combat effectiveness by working in conjunction with other air and space assets. StrikeStar's utility in performing any future missions would be limited only by its combat payload capacity and this limitation will be offset by revolutions in weapons technology that include lightweight, high-explosive, and directed-energy technology.[7] Yet, even by today's standards a StrikeStar could match the planned payload capacity of the Joint Strike Fighter (JSF).[8] Revolutions in conventional warfare will be driven by rapidly developing technologies of information processing, stealth, and long-range precision strike weapons.[9] A StrikeStar's relative invulnerability, endurance, and lethality would force redefinition of roles and missions and revolutionary doctrinal innovation for airpower employment.

For centuries war fighters labored to find the weapon that gave them a panoptic effect on the battle field.[10] The inherent flexibility and lethality of airpower provided us with great gains toward this long-sought goal.

However, limitations in technology, airframes, and the national purse have led to a less than ubiquitous presence over intended areas of operations. A StrikeStar could be the conduit to achieving this goal. The "kill boxes" of Desert Storm would give way to 24-hour "air occupation" of the AO. Airpower theorist Col John Warden states that the primary requirements of an air occupation platform in the future are stealth, long endurance, and precision.[11]

Not only could a StrikeStar hold the enemy at risk, it could produce unparalleled psychological effects through shock and surprise. In the words of Gen Ronald Fogleman, chief of staff, United States Air Force, "So, from the sky in the aerospace medium, we will be able to converge on a multitude of targets. The impact will be the classic way you win battles—with shock and surprise."[12] A StrikeStar could produce physical and psychological shock by dominating the fourth dimension—time.[13] Future CINCs could control the combat tempo at every level. Imagine the potential effect on enemies who will be unable to predict where the next blow will fall and may be powerless to defend against it.

The possibilities for joint force combat applications of this system are enormous. A StrikeStar could be a multiplier used to increase the tether of naval fleet operations or as a strike platform with marine expeditionary applications. It could be used as a high-value asset (HVA) escort or in combat air patrol (CAP), allowing assets normally tasked for these roles to be retasked for other missions. An example of a StrikeStar force enhancement capability is its potential use in tactical deception. A possible employment scenario could include a StrikeStar releasing air-launched decoys over an area of suspected surface-to-air missiles, and as enemy radars come on line to track the approaching decoys, the StrikeStar would destroy them.[14] It could then follow the strike package of F-22s or JSFs, loiter over the battle area, and perform near-real-time restrike as directed.

Concepts of Employment

In this section, concepts of employment describe the architecture required to employ the StrikeStar and detail the concept of operations in two notional operating modes. The final areas covered are critical tasks and weapons employment.

The System Architecture

The StrikeStar is inextricably linked to reconnaissance and command and control systems. The system architecture depicted in figure 5-2 illustrates how a StrikeStar is tied and integrated into the larger battle-space systems. Keep in mind that it is the entire architecture, or the system of systems, which enables mission accomplishment.[15] The StrikeStar is a relatively dumb system: it carries few sensors, and it is not designed for a great deal of human interface. The viability of the StrikeStar concept in 2025 depends on its ability to plug into the existing battle-space dominance and robust C^2.

Former vice-chairman of the Joint Chiefs of Staff Admiral Owens's prediction that the United States military will enjoy dominant battlefield awareness by 2010 is a prerequisite to this concept.[16] Dominant battle-space awareness in 2025 must include near-real-time situational awareness, precise knowledge of the enemy, and weapons available to affect the enemy.[17] This intelligence must be comprehensive, continuous, fused, and provide a detailed battle-space picture. The intelligence-gathering net will utilize all available inputs from aerospace assets, both manned and unmanned sensors.[18] The StrikeStar would rely on this integrated information for employment, queuing, and targeting. A StrikeStar in this architecture adds value since it enables an aerospace platform to provide dominating maneuver with lethal and precise firepower in a previously unattainable continuum of time. A pictorial representation of this concept is presented in figure 5-3.

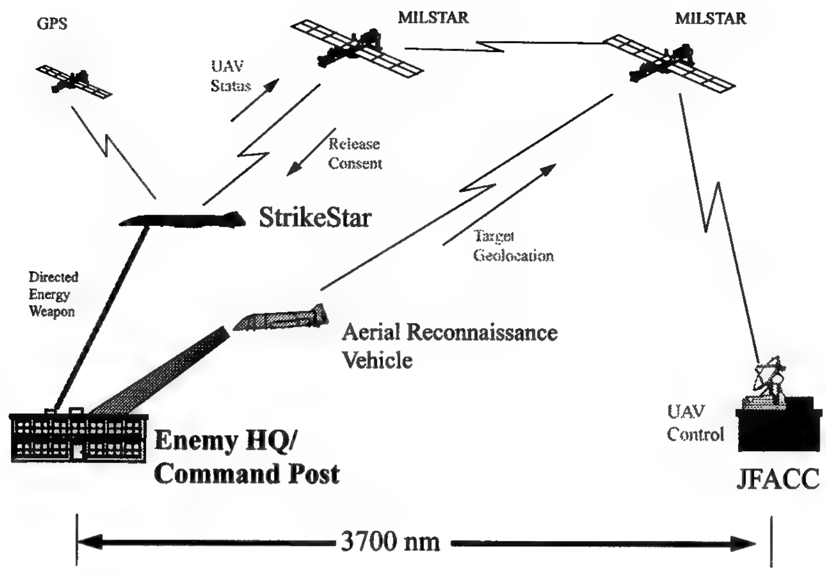

Figure 5-2. StrikeStar C^2 Architecture

Command and control capabilities in 2025 are the defining element in the StrikeStar concept. A StrikeStar would need to be fully integrated into a common C^2 element that manages all aspects of the air battle in 2025.[19] A StrikeStar places several unique demands on the command and control element. C^2 personnel would employ a StrikeStar by nominating targets, pulling down required intelligence, and selecting the platform and weapon to be used against them. The command element could then command weapons release or tie the StrikeStar directly to an AO sensor in an autonomous mode. In the autonomous mode intelligence is collected, sorted, and analyzed and then forwarded to a StrikeStar positioned to attack immediately a target by-passing the C^2 element (sensor-to-shooter).[20] To reduce vulnerability of the command center and StrikeStar, data-link emissions should be held to a minimum.

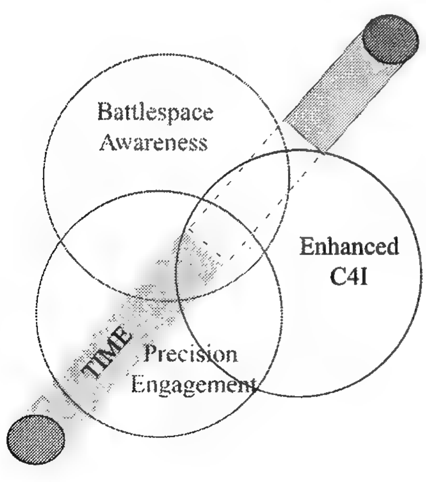

Figure 5-3. A System of Systems over Time Continuum

The type and location of the command center used in 2025 will depend on the nature of the conflict. Missions of the most sensitive nature, clandestine operations, or retaliatory strikes are best served by a short and secure chain of command. Therefore, these StrikeStar applications would be best served by a direct link to the platform from a command center located in the hub of political power. Similarly, if a StrikeStar is utilized in extremely hostile theaters, a

command and control center located far from hostilities is most advantageous. In low-intensity conflicts, peace enforcement, or domestic urban applications, the C^2 center could be moved to the vicinity of the conflict as a mobile ground station, an airborne platform, or even a space-based station.

Autonomous Strike Mission

The strike mission highlights the utility of a potentially autonomous mode of operation. This operating mode could free command and control center personnel to manage other assets. In the strike mode a StrikeStar would capitalize on the principles of simplicity, surprise, offensive, and objective.[21] The following details an autonomous strike mission (fig. 5-4).

Ground Operations. A StrikeStar is tasked from continental United States or a forward operating location to strike specific AO target(s). Mission specifics including target coordinates, time-on-target, takeoff time, and abort criteria are loaded directly into the aircraft computer via a physical link from the mission-planning computers. (The use of ground crew personnel is possible, however this option introduces potential for human error.)

Launch. StrikeStar performs premission diagnostic checks, starts, and taxis to meet its designated takeoff time. The aircraft would require improved taxiways and runways to support a notional, maximum gross operational weight of 24,000 pounds. Taxiways and runways must provide adequate obstacle clearance to accommodate a StrikeStar's 105-foot wing span. The runway length required will be approximately 4,000 feet for takeoff, landing, and abort distances. The StrikeStar would taxi via global positioning and airfield information. Mission support personnel would deconflict operations with ground control and tower or sanitize the airfield during ground operations and takeoff.

Climb Out. When operating in congested or controlled airspace it would be necessary to deconflict a StrikeStar with potential air traffic. In these cases the aircraft would be programmed to perform a spiral climb over the field until above the future equivalent of positive controlled airspace. (This may require coordination for airspace above and around the aerodrome for operations within the United States.)

En Route. The StrikeStar would proceed to the target as programmed unless updated information is passed from the command center. Integrated engine and airframe function indicators would be constantly monitored and adjusted automatically for peak performance by the Virtual Pilot. Engine anomalies will be compared against pre-programmed go/no-go criteria, and in the event an abort criterion is discovered, a message would be automatically passed to the C^2 center for action.

Ingress. A StrikeStar would proceed to the target via the programmed flight path. Although stealthy technology and altitude reduces vulnerability, flight path programming should integrate intelligence preparation of the battlefield (IPB) to optimize this technology and avoid obvious threats. Once in the AO the StrikeStar would release its weapons or recognize its assigned sensor and establish a "kill box." The kill box is a block of space where the StrikeStar releases weapons on threats identified by coupled sensors.[22]

Egress. StrikeStar would egress the AO using preprogrammed information or remain on-station in a preprogrammed orbit awaiting battle damage assessment (BDA) and potential retargeting information until egress was required.

Recovery. StrikeStar would fly to the airdrome's vertical protected air space, and execute a spiral descent unless otherwise directed. The aircraft would perform a precision approach and landing, taxi clear of the active runway, and return to parking, using the enhanced landing system (ELS) discussed earlier.

Regeneration. Maintenance time would be kept to a minimum through computer

diagnostics provided to ground personnel on landing, and blackbox swap technology. The aircraft could be refueled, rearmed, reprogrammed, and "turned" quickly after landing.

System Compromise. A StrikeStar is intended to be a durable platform, however system degradation due to battle damage or malfunction could compromise the platform. To ensure that classified programming information remains secure, preprogrammed information will be altitude volatile. Additionally, to prevent reverse engineering or endangerment of friendly forces, the airframe could be destroyed by onboard weapons or another StrikeStar in the event of an inadvertent landing or errant behavior.

Command-Directed Mission

The specifics of the command-directed mission overlap many of the aspects of the autonomous mission. The fundamental distinction between the two operating modes is that the command-directed mission requires command center inputs. In this operating mode, the StrikeStar could exploit the principles of unity of command, maneuver, mass, and economy of force. While the StrikeStar employment would naturally mesh with the tenets of aerospace power, this platform would define new limits to the tenets of persistence, flexibility, and versatility.[23] The objective of the command-directed mission is to provide continuous presence over the battlefield and maximize flexibility. Mission areas unique to command-directed missions are delineated below.

Ingress. A StrikeStar would be preprogrammed to a specific orbit where it would await closure of the C[2] elements OODA loop. This closure would provide the platform with the required information on optimum positioning and targeting commands.

Egress. A StrikeStar would remain on-station until fuel or weapons expenditures require a return to base. Fuel and weapons status will be provided to the command element on request. A return-to-base message will be transmitted at a predesignated navigation point. Due to the long loiter time in the AO, the planned recovery location may have changed, so updated landing information will be passed to the aircraft as situations dictate.

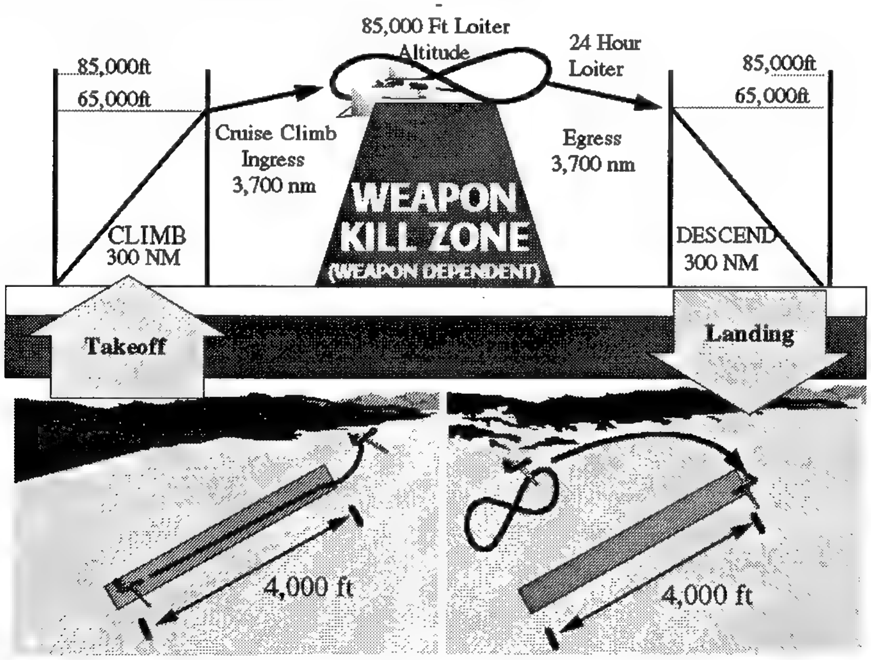

Figure 5-4. StrikeStar Mission Profile

Critical Tasks and Weapons Employment

The 2025 battle space will have both unique and familiar features. The StrikeStar could leverage available weapons technology to perform many critical tasks. As noted in the *New World Vistas*, there will be a number of tasks that must be accomplished. Among the most pressing tasks in 2025 will be the destruction of short-dwell targets, and theater ballistic missile defense.[24] Additionally, the potential of air occupation must be explored. A final task, well suited to a StrikeStar, would be covert action against transnational threats located in politically denied territory or in situations were plausible deniability is imperative.

The ability of a StrikeStar to loiter over an area for long periods and exploit information dominance with precision weapons, would make it a natural Theater Missile Defense (TMD) platform, particularly in boost phase intercept. A StrikeStar could be employed in the AO in a sensor-to-shooter mode looking for ballistic missiles in the first 180 seconds of flight. Intercepting missiles from high altitudes early in the boost phase increases the chances that dangerous debris would fall on enemy territory.[25] The weapon employed against TBMs or other short-dwell targets could be directed-energy weapons or hypersonic interceptor missiles.[26] The optimum weapons selection for a StrikeStar would match weapons availability to loiter capability. A StrikeStar offers the advantages of a space-based TBM defense weapon in terms of operational reach, a vast distance over which military power can be concentrated and employed decisively, and it extricates the military from the issues of the militarization of space.[27]

The StrikeStar approach to systems lethality and loiter capability could enable the Air Occupation concept. Because of a StrikeStar's endurance, altitude, and stealth characteristics, it could wait, undetected, over a specific area and eliminate targets upon receiving intelligence cues. If required for plausible deniability, specialized weapons could be used to erase any US fingerprint. Uniquely suited to a StrikeStar would be delivery of high-kinetic energy penetrating weapons. Firing kinetic weapons at StrikeStar's operational altitudes would allow engagements at longer ranges.[28]

Countries conform to the will of their enemies when the penalty of not conforming exceeds the cost of conforming. The cost can be imposed by destruction or physical occupation of enemy territory. In the past, occupation was conducted by ground forces—because there was no good substitute.[29] In 2025, a StrikeStar could send a lethal or nonlethal message to US enemies and enforce the imposition of our national will through air occupation across the battle-space continuum.

It is estimated that over half the nations of the world have active UAV programs.[30] Because of the proliferation of UAV technologies, the United States may face enemy UAVs similar to StrikeStar in the future. Although beyond the scope of this paper, consideration must be given to how a StrikeStar will fit into, and possibly shape the 2025 battle space. The broad influence that UAVs could have on military roles and missions will drive evolutionary changes in service doctrine. The issues of how best to employ strike UAVs, the details of the human-system interface, and potential countermeasures must be explored before this weapon system can fulfill its potential.

Notes

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Chapter 6

Conclusions

There will always be men eager to voice misgivings, but only he who dares to reach into the unknown will be successful. The man who has been active will be more leniently judged by the future.

–Gen Heinz Guderian
Armored Forces

Many important issues face our military's leadership over the next 30 years. Continuing to build a reliable force structure amidst shrinking budgets is a challenge that must be met head-on. Recognizing the opportunity for growth beyond the UAV's reconnaissance mission is a must if the US military is to be ready for all aspects of the conflict spectrum. While there are other near-term priorities for military spending, UAV development beyond reconnaissance requires specific funding for research and development, and operations and maintenance. Estimating seven years for development and three years from initial fielding to a full operational capability, the lethal UAV concept should be supported and funded no later than 2015. In reality, this milestone should be achieved earlier, but we live in an imperfect world and funding for our future force is only growing smaller.[1]

The technologies discussed here are realizable by 2025. Current UAV advanced concept technology demonstration (ACTD) efforts by Defense Airborne Reconnaissance Office's (DARO) will provide the leverage we need to take the next step in UAV missions. Current efforts to improve conventional weapons and produce an airborne-directed energy weapon will provide the required precision and lethality needed to operate across the full spectrum of conflict. An interconnected, highly distributed infosphere that produces ultimate battle-space awareness will provide the C^2 reins to provide the conventional deterrence desired. Conventional fuel sources can provide the desired platform performance between now and 2015, but continued research to provide cleaner fuel sources and improved fuel efficiencies is desirable. StrikeStar technology is a small hurdle—a challenge that can be overcome by funding and support from visionary leaders.

UAVs have a great potential for the strategic and operational commander in the pursuit of national interests. To optimize that potential, the apparent pro-pilot bias that favors manned aircraft over UAVs must be overcome. In addition, leaders must find ways to fund lethal UAV development and support the research and development of doctrine to support it. While doing so, leaders must also ensure that lethal UAVs and their concept of operations comply with the wishes of a public that demands safety and accountability.

Based on these conclusions, the following are recommended:

- Add a budget line in the FY00 POM, or sooner, that provides adequate funding for the ACTD. Based on the ACTD results be prepared to dedicate funding for lethal UAVs.

- Initiate an ACTD effort that picks up where the current DARO ACTDs end. The ACTD will focus on integrating components produced in the Miniaturized Munitions Technology Demonstration, LOCASS, and Pave Pace avionics architecture, with an enlarged variant of the DarkStar platform.
- Investigate a multimission modular payload configuration for UAV use that will allow a quick and economical reconfiguration from strike to reconnaissance missions.
- Continue work on an airborne laser, focusing on miniaturizing the weapon.
- Investigate possible TMD weapons for boost-phase intercept or attack operations for carriage on a long endurance stealthy UAV.
- Initiate a study to determine what doctrinal changes are needed to effectively employ StrikeStar across the conflict spectrum.
- Accelerate efforts to fuse all-source national and theater intelligence technologies .
- Initiate a study to determine how lethal UAVs can be integrated into force structure and the cost benefits of this concept versus alternatives.
- Continue strong support of a global information infrastructure that can provide secure, reliable communications.

The long-endurance multimission lethal UAV offers the war fighter of the twenty-first century a capability to enforce the concept of "air occupation." Applicable for use over a wide variety of scenarios and levels of warfare, the StrikeStar would be an affordable power projection tool that overcomes many of the political and social issues that will hinder force projection and force employment in the next century.

Note

1. Maj Gen John R. Landry, USA, Retired, National Intelligence Officer for General Purpose Forces, Central Intelligence Agency, address to the ***2025*** Study Group, Maxwell AFB, Ala., 14 February 1996.

Appendix A

Unmanned Aerial Vehicle Reliability

UAV reliability constantly comes up as a major factor when conducting cost performance trade-offs between manned and unmanned aircraft. The sporadic interest in UAVs has resulted in missing reliability data or insignificant data collections due to small UAV test sets, and various measurement techniques. The propensity to link payload performance to UAV platform reliability also led to misconceptions on overall reliability.

Table 4 shows the first data collected on the Air Force's first widespread use of UAVs during the Vietnam War and its aftermath. The percent returned varied significantly from model to model. The fact these UAVs were flying in a war zone probably accounts for many of the losses, but the inability to recover downed UAVs prevented an exhaustive analysis. Using the AQM-34L as the largest statistical data set, it is easy to assert that the percent returned represents a reliability approximation that is good, but does not meet the reliability rates seen in manned aircraft.

Data on the Pioneer UAVs shows the accident rate is still higher than manned aircraft, but some improvement is noted since 1986 as the system matured (table 5).

Data on the Hunter UAV is shown in table 6. The percentage return rate was 99.7 percent when human error is excluded and only hardware/software causes are used. The data reflects results from both early technical and user testing as well as follow-on early training for the Hunter System. There were a total of 12 strikes (UAVs damaged such that they will never return to flight) out of the total 1,207 sorties flown. Human error was assessed as the primary cause for 66 percent (8) of the 12 strikes/losses. Hardware/software was assessed as the cause for the remaining 34 percent (4) of the strikes. Of the 12 losses, 66 percent (8) occurred during training flights while 34 percent (4) were lost during the early technical or demonstration tests.[1]

The latest Predator UAV data is shown in table 7. The Predator has been supporting reconnaissance missions in Bosnia and two UAVs have been lost: one to ground fire (Predator 8) and one to an engine malfunction (Predator 1). Used for training now, the GNAT-750 was originally developed for the Central Intelligence Agency and was also used in Bosnia.

Note

1. Mr Bill Parr, US Army Joint UAV Office, Redstone Arsenal, Ala., provided the Hunter data and crash data on 2 April 1996.

Table 4
Ryan Model 147 UAV Flight Statistics

RYAN 147 Model	MIL Model	LT	SP	Mission	Date Opr	Number Launch	Percent Returned	Msn Per UAV
A		27	13	Fire Fly-first recce demo	4/62–8/62			
B		27	27	Lightning Bug First Big-Wing High Alt PhotoBird	8/64–12/65	78	61.5	8
C		27	15	Trng and Low Alt Tests	10/65			
D		27	15	Electronic Intelligence	8/65	2		
E		27	27	High Alt Elect Intel	10/65–2/66	4		
F		27	27	ECM	7/66			
G		29	27	Long body/larger engines	10/65–8/67	83	54.2	11
H	AQM-34M	30	32	High Alt Photo	3/67–7/71	138	63.8	13
J		29	27	First Low Alt Day Photo	3/66–11/77	94	64.9	9
N		23	13	Expendable Decoy	3/66–6/66	9	0	
NX		23	13	Decoy and Med Alt Day Photo	11/66–6/67	13	46.2	6
NP		28	15	Interim Low Alt Day Photo	6/67–9/67	19	63.2	5
NRE		28	13	First Night Photo	5/67–9/67	7	42.9	4
NQ		23	13	Low Alt Hand Controlled	5/68–12/68	66	86.4	20
*NA/NC	AQM-34G	26	15	Chaff and ECM	8/68–9/71			
NC	AQM-34H	26	15	Leaflet Drop	7/72–12/72	29	89.7	8
NC(ml)	AQM-34J	26	15	Day Photo/Training				
S/SA		29	13	Low Alt Day Photo	12/67–5/68	90	63.3	11
SB		29	13	Improved Low Alt Day Photo	3/68–1/69	159	76.1	14
SRE	AQM-34K	29	13	Night Photo	11/68–10/69	44	72.7	9
SC	AQM-34L	29	13	Low Alt Workhorse	1/69–6/73	1651	87.2	68
SC/TV	AQM-34L/TV	29	13	SC with Real-time TV	6/72–	121	93.4	42
SD	AQM-34M	29	13	Low Alt Photo/ Real-time Data	6/74–4/75	183	97.3	39
SDL	AQM-34M(L)	29	13	Loran Navigation	8/72	121	90.9	36
SK		29	15	Operation From Carrier	11/69–6/70			
T	AQM-34P	30	32	High Alt Day Photo	4/69–9/70	28	78.6	
TE	AQM-34Q	30	32	High Alt Real-time COMINT	2/70–6/73	268	91.4	34
TF	AQM-34R	30	32	Improved Long-range	2/73–6/75	216	96.8	37
						3435		

Source: William Wagner, *Lightning Bugs and Other Reconnaissance Drones* (Fallbrook, Calif.: Aero Publishers, Inc., 1982).

Table 5
Pioneer UAV Flight Statistics

Year	# Mishaps	Flight Hours	Sorties	Percent Sorties Loss	Percent Sorties Accident
1986	5	96.3	94	2.1	5.3
1987	9	447.1	279	2.5	3.2
1988	24	1050.9	577	1	4.1
1989	21	1310.5	663	1.2	3.1
1990	21	1407.9	668	<1	3.1
1991	28	2156.6	845	1.3	3.3
1992	20	1179.3	676	1	2.9
1993	8	1275.6	703	1	1.1
1994	16	1568.0	862	1	1.8
1995	16	1752/0	692	4	2.3

Source: Commander Davison, US Navy's Airborne Reconnaissance Office, 15 March 1996.

Table 6
Early Hunter UAV Flight Statistics

Date of Operations	Number of Sorties	Percent Returned	Average Flight Duration
1/1/91–2/20/96	1207	99.0	2.97 hours

Table 7
Predator UAV Flight Statistics

Model	Date OPR	Total Flights	Total Flight Hours	Bosnia Flights	Bosnis Flight Hrs	Percent Returned
GNAT-750	9/94–2/96	73	161			100
Predator 1	6/94–8/95	74	328	10	60	94
Predator 2	9/94–8/95	87	452	23	145	100
Predator 3	11/94–10/95	50	205	29	128	100
Predator 4	9/95–2/96	47	132			100
Predator 5	2/95–11/95	99	301			100
Predator 6	3/95–2/96	28	90			100
Predator 7	5/95–2/96	18	42			100
Predator 8	7/95–8/95	11	41	4	20	92
Predator 9	8/95–2/96	74	476	49	371	100
Predator 10	8/95–10/95	19	147	15	127	100
		580	2,375	140	851	

Source: Manny Garrido, director of Advanced Airborne Systems, Battlespace Inc., Arlington, Va., 22 February 1996.

Appendix B

Worldwide Unmanned Aerial Vehicles

Steven J. Zaloga's article "Unmanned Aerial Vehicles" in the 8 January 1996 issue of *Aviation Week & Space Technology* provides a comprehensive listing of ongoing efforts in UAV production (table 8). Thirty-four companies, including 16 US companies, are represented here. Nine countries besides the United States are involved in UAV design and production. Included in this group are many peer competitors or nations involved in arms exports.

Table 8
Worldwide UAV Systems

Manufacturer	Type	Mission	Weight	Payload	Speed	Endurance	Max. Alt
AAI							
Hunt Valley, Md., USA	Shadow 200	Multimission	250	Various	100+	3+ hr	15,000
	Shadow 600	Multimission	600	Various	100+	12+ hr	17,000
Adv Tech & Engr Co.							
(Pty) Ltd.,South Africa	UAOS	Multimission	275	Optronic Day Sight	100	3 hr	16,400
Aero Tech							
of Australia Pty, Ltd.	Jundivik Mk 4A	Target	4,000	—	M 0.86	115 min	—
Aerovironment Inc.							
Simi Valley, Calif., USA	C. 22	Target	1,210	Radio cmd (R/c)	M 0.95	2.5 hr	—
	HILINE	HALE Recce	770	Autop datalink, nav computer	120 loiter	1–2 days	40,000
	Pathfinder	HALE Recce	480	Comm relay, environ sensing	—	—	75,000
	Pointer	Multipurpose/ Recce	8 lb	R/c	25–50	2 hr	2,000
	SASS-LITE	Multimission	800 lb	Autop	27	4 hr	5,000
Aurora Flight Systems							
Manassas, Va., USA	Chiron	Marine Science	4,630	Scientific	100	24 hr	10,560
	Perseus A	Atmo. Science	1,750	Atmospheric sampling	80	5 hr	74,000
	Perseus B	Atmo. Science	2,500	Atmospheric sampling	80	36 hr	63,000
	Theseus	Atmo. Science	8,800	Scientific	50	48 hr	90,000
CAC Systems							
Vendomôise, France	ECLIPSE T1	Target	300	IR & RF equip	M 2.5	ballistic	42,000
	ECLIPSE T2	Target	450	IR & RF equip	M 4.3	ballistic	70 mi
	FOX AT1/AT2	Recce/surv	160/250	R/c, program	160	22 hr/5 hr	10,500
	FOX TS1	Target	160	Autop, GPS	190	1 hr	10,500
	FOX TS3	Target	240	Autop, Nav, GPS	280	1 hr	15,800
	FOX TX	Electronic warfare	250	Autop, Nav, GPS	160	5 hr	10,500

Table 8—continued

Manufacturer	Type	Mission	Weight	Payload	Speed	Endurance	Max. Alt
Canadair, Bombardier Inc.							
Montreal, Quebec, Canada	AN/USD-501	Surv/target acq	238	Programmed	460	75 nm	—
	AN/USD-502	Surv/target acq	—	Programmable	—	—	—
	AN/USD-502	Surv/target acq	—	Programmed	—	—	—
	CL-227	Surv/target acq	502	R/c, prog	92	4 hr	—
	CL 289	Recce and surv. target acquisition	529	Optical camera, IRLS	460	1,242 mi	1,970
Daimler-Benz Aerospace							
Dornier, Germany	DAR	Antiradar	264.5	Pass radar seeker	155	3 hr	9,840
	Seamos	Maritime surv	2,337	Radar, EO	103	4.5 hr	13,125
	SIVA	Recce, surv, target acq	441	Flir, CCD, TV	92	8 hr	8,200
Flight Refueling Ltd.							
Winborne, Dorset, UK	Raven	Surv/Recce	185	Video, Flir	75	3 hr+	14,000
Freewing Aerial Robotice							
College Park, Md., USA	Scorpion 60	Multipurpose	110	Various 25 lb	100	3–4 hr	5,000
	Scorpion 100	Multipurpose	320	Flir, EO, 50 lb	172	4 hr	15,000
General Atomics							
San Diego, Calif., USA	BQM-34A	Target	2,500	R/c	690	692 nm	—
	J/AMQ-2	Target	519	R/c	M 0.9	15.6 min	—
	Altus	High alt research	1,600	—	130	48 hr	50,000
	GNAT 750	Recce/surv/target	1,126	Day TV, Flir	150 kt	40 hr	25,000
	I-GNAT	Recce/surv/target	1,140	Day TV, Flir	175 kt	60 hr	32,000
	Predator	Recce/surv/target	2,085	Day TV Flir, SAR	120 kt	60 hr	25,000
	Prowler-CR	Recce/surv/target	200	Day TV, Flir	160 kt	8 hr+	20,000
Honeywell, Defense							
Avionics Systems Div	QF-104J	Target	23,690	—	M2.2	—	—
Albuquerque, N.Mex., USA	QR-106	Target	35,411	—	M2.2	—	—
	QR-55	Target	7,000	—	133	—	—
Israel Aircraft Industries,							
Malat Div. Tel Aviv, Israel	Eyeview	Recce, surv, & target acq	174	Varies	120 kt	4–6 hr	10,000
	Helistar	OTH target acq, Recce, & surv	2,450	Computer	100 kt	4.5 hr	—
	Heron	Multipurpose	2,400	—	125	52 hr	32,000
	Hunter	Recce/surv	1,600	—	110	12 hr	15,000
	Pioneer	Recce/surv	430	Computer	90 kt	6.5 hr	—
	Searcher	Recce/surv	700	Computer	110 kt	24 hr	—
Kaman Aerospace							
Bloomfield, Conn., USA	QUH-1B,C,E,M	Target	9,500	Radar command Digital control	126	155 min	—
Kamov Design Bureau							
Moscow, Russian Fdr	Ka-37	Recce, comm	550	Preprog or r/c	59 kt	4.5 min	5,200
Lear Astronautics Corp.							
Santa Monica, Calif., USA	Skyeye R4E-50	Multipurpose	780	125	8+ hr	15,000+	—

Table 8—continued

Manufacturer	Type	Mission	Weight	Payload	Speed	Endurance	Max. Alt
Lockheed Martin Skunk							
Works Palmdale, Calif.,USA	DarkStar	Acq/Recce/surv	8,600	SAR	288+	8+ hr	45,000+
Lockheed Martin							
Electronics & Missiles	AQM-127A	Target, SLAT	2,400	Inertial, radar	M 2.5	55 nm	—
Orlando, Fla., USA		(Super Sonic Low)					
Meteor Acft & Electronics							
Rome, Italy	Mirach 20	surv/target/acq	374	R/c, prog	120	240+	—
	Mirach 26	surv/target/acq	440	R/c, prog	135	420+	—
	Mirach-70	Target	525	R/c	195	60	—
	Mirach-100/4	Target	594	R/c, prog	M0.8	60	—
	Mirach-150	Recce	748	R/c, prog	M0.7	80	—
Mission Technologies							
Hondo, TS, USA	Hellfox	Multimission	240	Flir, TV, other	80 kt	4 hr	15,000+
Northrop Grumman Corp.							
Los Angeles, Calif., USA	BQM-74E	Target	595	R/c	530 kt	—	—
People's Rep of China							
	B-2	Target	123.5	R/c	149	1 hr	—
	Changkong IC	Target	5,401	R/c	565	45 min	—
	D-4	Target	308	R/c	106	2.6 hr	—
Raytheon Acft Co., (Beach)							
Wichita, KS, USA	AQM-37	Target Variant	620	Radio cmd/prog	M4.0	120 nm	—
	AQM-37A	Target	560	Programmed	M0.7-2	120 nm	—
	AQM-37C	Target	581	Radio cmd/prog	M1.0-3	120 nm	—
	AQM-37EP	Target	600	Radio and preprog autopilot	M3.0-4	120 nm	—
	MQM-107B/D	Target	1,012	Radio cmd/prog	M0.80	90m/100m	—
	MQM-107D Upgrade	Target	1,012	Radio cmd/prog	M0.80	100 min	—
	MQM-107E	Target	1,012	Radio cmd/prog	M0.85	100 min	—
SAGEM							
Paris, France	Crecerelle	Recce/surv/target	265	Flir, EW	155	5 hr	15,000
	Marula	Recce/surv/target	165	Flir, EW	155	5 hr	15,000
Scaled Composites							
Mojave, Calif., USA	Raptor 2	Environ research	2,000	Environ. sensors	92	10 hr	65,000
Sikorsky							
Stratford, Conn., USA	Cypher	Recce	250	EO, Flir	60	3 hr/2,500	7,900
Silver Arrow							
Rishon-Lezion, Israel	Colibri	Pilot training	50	—	31–100	2 hr	10,000
	Hermes 450	Multipurpose	1,000	Various <350 lb	57–115	25 hr	23,000
	Micro-Vee	Tactical UAV	100	Video camera	50–126	5 hr	15,000

Table 8—continued

Manufacturer	Type	Mission	Weight	Payload	Speed	Endurance	Max. Alt
STN Atlas Electronik							
Bremen, Germany	Brevel	Recce/surv/target	330	Thermal Imaging camera	136	5.5 hr	11,500
	Luna	Optical Recce	44	TV, Flir	124	2 hr	3,300
	Tucan-95	Recce/surv/target	330	TV, Flir	155	10 hr	13,100
Strela Production Assn.							
Orenberg, Russian Fed	La-17MM	Target	5,070	Transponder	560	1 hr	—
	La-17R	Recce	6,835	Camera	560	1 hr	—
	Dan	Target	760	Transponder	440	40 min	—
Tadiran Israel Electronic							
Industries Ltd., Israel	Mastiff Mk 3	Recce/surv & target acq	254	R/c; prog	100	7+ hr	—
Target Technology Brux,							
France & Ashford, UK	Banshee 1	—	190	Flares	54–200	1.5 hr	23,000
	Banshee 2	—	190	Flares	57–236	1.5 hr	23,000
	IMP	Operator Training	—	—	15–90	0.5 hr	—
	Petrel	Ballistic Target	—	—	M3.0	104 min	—
	Snipe Mk 5	Aerial Target	145	Flares	180	1.2 hr	18,000
	Snipe Mk 15	Aerial Target	—	Flares	130	0.5 hr	5,000
	Spectre	Surveillance, EW	—	CCD camera	77–150	3–6 hr	23,000
Teledyne Ryan Aero.							
San Diego, Calif., USA	324	Recce	2,374	Program command	M0.80	1,400 nm	—
	Teledyne 410	Recce/surv	1,800	Program command	169 kt	14 hr@10K	—
	BQM-34A	Target	2,500	RPV Trk Cntrl Sys	M0.97	692 nm	—
	BQM-34S	Target	2,500	Integ Trk Cntrl Sys	M0.97	692 nm	—
	MQM-34D	Target	2,500	DTCS	M0.97	692 nm	—
	BQM-145A	Recce	2,000	Programmable	M0.91	700 nm	—
	Tier 2+	Recce	24,000	—	395	42 hr	67,300
	YBQM-145A	Recce	2,000	Program command	M0.91	700 nm	—
Tupolev Design Bureau							
Moscow Russian Fed	DBR-1 Jastreb	Recce	84,875	Camera or Elint	1,740	1.5 hr	—
	VR-2 Strizh	Recce	15,400	Camera	685	1 hr	—
	VR-3 Reys-D	Recce	3,110	Camera or TV	595	15 min	—
Westinghouse Electronic							
Huntsville, Ala., USA	Star-Bird	Recce, surv, C101 & target acq	280	Flir, TV	—	6.5 hr	—
Yakolev Design Bureau							
Moscow Russian Fed	Shmel	Surv, EW	286	R/c uplink	97 kt	2 hr	9,850
	Yak-060	Recce, EW	225	TV or EW jammer	110	2 hr	—
	Yak-061	Recce	285	TV	110	2 hr	—

Source: Tim H. Storey, director of Operations, Teal Group Corporation, Fairfax, Va.

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Space Operations: Through the Looking Glass (Global Area Strike System)

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Executive Summary

America's capability to operate in space is increasing with every passing day. Space operations are already recognized as a crucial part of all American military operations. Military space operations may be indirect, through such staples as navigation, communications, and surveillance/reconnaissance support to the war fighter, or direct, through development and fielding of a range of responsive directed energy and kinetic energy weapons. A modest fleet of flexible, mission-tailored transatmospheric vehicles (TAV) has an important place in any thoughtful space operations architecture, providing the only conceivable way to insert human presence rapidly into the fast-breaking crises of 2025. Space represents the future—a future in which aerospace power will increasingly be projected through space systems.

This paper advocates a "system-of-systems" architecture for an American global space-strike capability in 2025. This architecture recognizes the importance of the global information network (surveillance and reconnaissance combined with the intelligence system), the military command and control system, the perennial space "utilities" (communications, navigation, and weather), and a robust readiness and sustainment system to enable the fielding of space-based or space-borne weapon systems. The weapon system itself is described as a smaller system-of-systems composed of the weapon, its platform, and a primarily off-board surveillance, acquisition, and tracking/battle damage assessment capability provided through the global information network.

After a review of the alternatives for a global space-strike system in 2025, the optimum solution appears to be combining a prompt response capability with a complementary flexible response capability. The prompt response capability is best provided by a system of Continental United States (CONUS)-based laser devices that bounce high-power directed energy beams off a constellation of space-based mirrors. Inherently precise, megawatt-class, light-speed weapons can potentially act within seconds or minutes to resolve the rapidly developing crises of 2025. Flexible response is best provided with a small CONUS-based fleet of TAVs equipped with a variety of payloads, including kinetic-energy weapons, compact laser weapons, and special forces squads. Responding within a few hours of notification, a TAV can precisely deliver force and/or adaptable human judgment to crisis locations anywhere on earth.

The balance of influence in the information technologies has shifted from the Department of Defense to commercial organizations. This trend will continue and accelerate between now and 2025. The crucial importance of detailed, timely knowledge and rapid, ultrawideband communications to military space operations will demand the extensive use of commercial (possibly international) space systems and technologies. The world of 2025 will see a crowded "sky" filled with space systems shared by military and government organizations on the one hand and commercial concerns on the other.

Chapter 1

The World of 2025

Once again a small but capably armed country is threatening to seize its smaller but resource-rich neighbor. The Global News Network reports that the border has been violated. The same old story? No, the plot twists as a sophisticated satellite surveillance and reconnaissance system tracks the belligerent nation's leader. As he steps to the podium to incite his troops to greater violence, a blinding light from above vaporizes him and his podium, leaving even his bodyguards untouched. His smarter brother, the second in command, countermands the invasion orders and in 12 hours the borders are restored. Stability, if not peace, reigns again.

This is not science fiction, but a mission well within the capabilities of space operations in 2025. By that year space operations will become the key to a wide range of military missions. Current US military space systems are an important force multiplier, but they do "not yet provide the seamless, reliable, rapidly delivered information needed by the modern war fighter."[1] To resolve this deficiency, space system designers must make a clean break with the expensive, large-scale, hand-built designs of 1996 and move to a new approach that emphasizes economy, efficiency, and operational utility in dynamic balance with rapidly evolving technological developments.

This paper highlights the importance of the full range of space operations while emphasizing the point that, in 2025, the United States must have a global space-strike capability. Why is this capability essential for military operations in 2025? All nations are becoming highly dependent on space assets for communications, weather forecasting, navigation and positioning, and surveillance and reconnaissance, and this dependency is growing at an exponential rate. To preserve the ability to use space and to deny space to aggressors, the US must have control of space. This need to control space will quickly overcome the political will to oppose weapons in space. Once this line is crossed—and its crossing is inevitable—we must be equipped to make use of space in a variety of novel ways.

The rapidly accelerating rate of technological change virtually assures that, by 2025, even the poorest nations will have access to electronic information and decision-making aids only dreamed of today. The average time required to complete an Observation, Orientation, Decision, and Action (OODA) loop will be much shorter in 2025.[2] In such a world, the US must be able to take rapid action (measured in minutes or perhaps even seconds) to resolve conflict situations before they can grow out of control. The essential capabilities of *timeliness* or *responsiveness* can certainly be provided by a properly designed space-strike system and perhaps only by such a space-strike system.

Because the world of 2025 will provide smaller countries and organizations with far greater abilities to disrupt our nation and its allies, we will need measures *flexible* enough to produce effects across the full range of the "spectrum of force," ranging from the nonlethal (deceit, delay) to the lethal (damage, destruction). The requirement to produce the right effect on the right target at the right time is as desirable in a space-strike system as it is in today's more familiar combat systems.

The Space Operations Mission

The heart of the space operations mission is the *global presence* concept as encapsulated in the following summary from the Department of the Air Force *Global Presence 1995* document:

> As we peer into the future, we should view *Global Presence* as one route the Services can take to achieve our country's ever evolving national security objectives. We in the military possess the means, physical and virtual, to provide America continuous awareness of world events and a force capable of projecting military power worldwide, in minutes or hours, with little or no warning.[3]

While the notion of global presence is a concept of 1996, its principle will remain a constant for decades to come. The name may change, but the mission will remain crucial as long as the United States wishes to remain a world power. Much of America's global presence already depends on the world's highest technology systems operating freely from "the high ground of space." The only essential element missing in 1996 is a force projection capability operating through the space environment (see appendix A).

In the fast-paced world of 2025, the volume of space near earth (at and below geosynchronous orbit) will be filled with the space assets of many, if not all, nations. The commercial, civil, and military possibilities inherent in the high ground of space will be fully exploited. These future space systems will be distributed and interconnected in ways we can only dimly imagine today. It may even be impossible to point at any single piece of space hardware and say "this belongs to the United States." Instead, a nation and nongovernmental organizations (NGO) may use various parts of various space assets at different points in time.

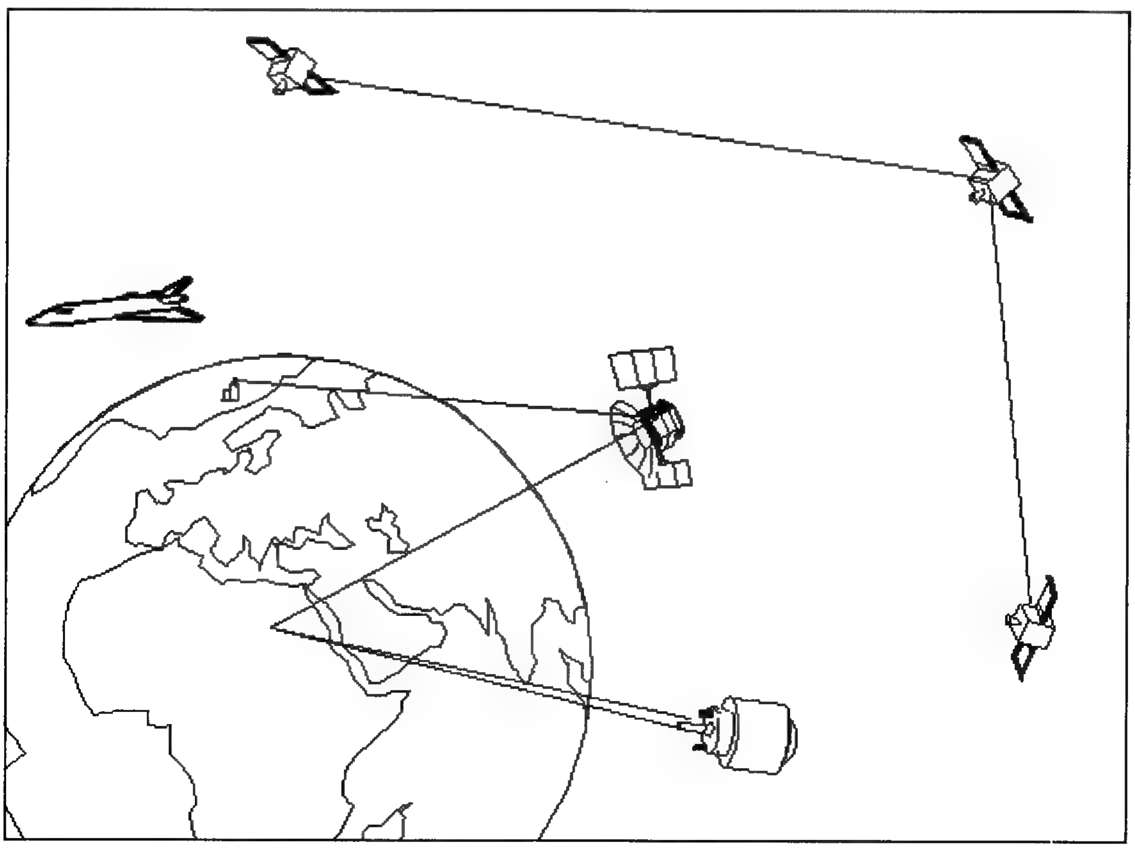


Figure 1-1. The View from Space

The Topic of Discussion

The military's space support and space-control missions in 2025 are described in other ***2025*** white papers. The force enhancement mission is addressed from several points of view in other white papers involving surveillance and reconnaissance and information operations.[4] This paper will concentrate primarily on the space force application mission and those elements of force enhancement which relate directly to the military application of force through the medium of space.

Issues Involving Space Operations in 2025

Several trends are already evident in the world of 1996 that will fundamentally influence all future operations in space. Although the precise impact of these trends cannot be predicted with confidence, certain broad conclusions appear inescapable.

Manned versus Unmanned Systems

For years, the "proper place" for manned and unmanned space vehicles has remained unchanged. Deep space, long-duration planetary exploration has been performed by unmanned robotic space probes. Space-based communication, remote sensing, weather, and navigation missions are also performed with sophisticated unmanned platforms well suited to operation in the hostile environment of space. Manned missions are limited to complex scientific and (frankly) public relations endeavors.

Considering the likely advances in telepresence, virtual reality, and wideband communications linked with secure, reliable, remote piloting techniques, there will probably be no requirement for a sustained human presence in space through at least the 2025 time frame, at least in regard to military missions. With the single exception of limited space sorties delivered by transatmospheric vehicles, all of the space systems discussed in this paper are hosted by unmanned platforms.

Large versus Small Satellites

The conventional approach to space systems involves large satellites (weight in excess of 500 kilograms) containing as many multimission payloads as will fit on the booster. The emphasis on high-volume, high-weight satellites has contributed to the enormous cost of developing and fielding space systems. A recent, and very attractive, alternative involves the use of small (weight below 500 kilograms) or even micro (weight below 50 kilograms) satellites launched by cost-effective boosters such as the Orbital Sciences Corporation's Pegasus. Commercial remote-sensing satellites are already being developed with a panchromatic spatial resolution as good as one meter and multispectral resolutions below 20 meters.[5] Other uses for small and microsatellites will develop naturally as an outgrowth of continuing advances in the areas of materials, small sensors, miniaturized electronic and mechanical systems, inexpensive space launch, and packaging.[6] Soon, satellites will no longer need to be large, heavy structures overloaded with redundant systems. Small and microsatellites will be able to perform all the functions carried out by today's large, "one-of-a-kind" satellites.

Ground versus "Anywhere" Processing and Delayed versus Near-Real-Time Information

The volume of scientific and intelligence data, including high-resolution imagery, is growing at an alarming rate. To handle this increased traffic, it will be necessary to install ever more capable onboard processing power on satellites equipped with advanced visible, infrared, and radar sensors. By 2025, it should be possible to process even the most complex images onboard in real time.[7] Full image data sets will no longer need to be transmitted to central ground stations for slow postprocessing. These real-time images can then be "fused" with other forms of militarily significant intelligence information, in near real time, and at any location desired—all made

possible by microprocessors perhaps a million times more capable than anything we possess today. Combined with high-volume, high-bandwidth communications (perhaps laser communications), the military commander's dream of understandable, near-real-time information on demand will finally be possible. The "fog of war" will not be fully lifted in this way, but it will be significantly thinned.

Military versus Cooperative/Commercial Endeavors

The end of the cold war and the subsequent decline in military budgets has forced the US Air Force to reconsider its traditional posture on space operations. Every day, more foreign governments and commercial concerns are gaining access to space, turning near-earth orbit into a very busy place. Technologies once driven solely by US government dollars are increasingly dominated by private funding. Clearly, significant opportunities exist for the US Air Force to share the assets (and technological developments) of commercial concerns and even foreign governments to accomplish important missions such as communications and remote sensing.[8] In particular, the large civilian investments in electronics, sensors, advanced communications, and information systems will soon exceed the military's research budget in these areas. Long before 2025, the US military must learn to adapt the technological developments of others to meet national security needs. This will not exempt us from our need for space superiority, and actually will drive our need for greater technological superiority in a variety of areas.

In the year 2025, military space operations will be augmented by vastly improved passive and active sensors, producing the nearly continuous global surveillance and reconnaissance capability (sometimes called "global awareness") required to project power on a global scale flexibly and effectively. These improvements will include the capability to detect and track fixed and mobile targets in all weather conditions with sensors accurate enough to provide useful battle damage assessment.[9] This will be possible not through military-specific technological advancements but through synergistic civil, military, and international developments. All of these abilities will again be essential for a nation that desires space superiority and the capability to project force from space.

Notes

1. David J. Lynch, "Spacepower Comes to the Squadron," *Air Force Magazine* 77, no. 9 (September 1994): 66. According to Brig Gen David L. Vesely, first commander of the Air Force Space Warfare Center, "When we got to the war, space resources were available, but were not tailored to the war fighter's problem. Tactical warning was just not there. Likewise, reconnaissance data all arrived, but we did not get what was tactically useful."

2. John R. Boyd, "A Discourse on Winning and Losing" (A collection of unpublished briefings and essays. Air University Library, Document No. M-U 43947, August 1987).

3. Gen Ronald E. Fogleman, USAF, and Sheila E. Widnall, *Global Presence 1995* (Washington, D.C.: Headquarters USAF, pamphlet, 1995), 16.

4. Lt Col Bruce W. Carmichael et al., "Strikestar ***2025***," ***2025*** Study (Maxwell AFB, Ala.: Air War College, 1996). See also CDR Clarence E. Carter et al., "The 'Man in the Chair' - Cornerstone of Global Battlespace Dominance"; Lt Col Edward F. Murphy et al., "Information Operations: Wisdom Warfare for 2025"; Lt Col William Osborne et al., "Information Operations: A New Warfighting Capability"; and Maj Michael J. Tiernan et al., "In-Time Information Integration System (I^3S)," ***2025*** Study (Maxwell AFB, Ala.: Air War College, 1996).

5. Sarah L. Cain, "Eyes in the Sky: Satellite Imagery Blasts Off," *Photonics Spectra*, October 1995, 90–104; and Maj Timothy Hawes, USAF, "Commercial Use of Satellite Imagery," *Program Manager* 24, no. 2 (March–April 1995): 44–47.

6. Gregory Canavan and Edward Teller, "Strategic Defense for the 1990s," *Nature* 334 (19 April 1990): 699–704.

7. Information obtained from a senior US Air Force professional speaking to the Air War College under the promise of nonattribution.

8. Lt Col Larry D. James, USAF, "Dual Use Alternatives for DoD Space Systems," Research Report (Maxwell AFB, Ala.: Air War College, April 1993), 31.

9. Canavan and Teller, 699.

Chapter 2

Required Capability

The US must ultimately control the high ground of space by attaining and maintaining space dominance through the use of space systems. A system-of-systems space-strike architecture must be developed that consists of five major components: (1) a global information network (surveillance and reconnaissance system, intelligence system); (2) a secure command and control system; (3) certain key utilities (communications, navigation, and weather); (4) a comprehensive readiness and sustainment system; and (5) a space-strike weapon system or combination of weapon systems. The architecture for a particular mission might consist of the weapon plus sensors and/or communications integrated on a single, space-based platform, or all parts of the system might be distributed across a number of platforms based in different mediums (space, air, sea, land, subsurface). The actual location of the various components should be determined by the outcome of a complicated systems analysis process that considers many cost-effectiveness and mission-effectiveness factors. Only mission-effectiveness factors will be addressed in this chapter.

Every weapon system possesses, to greater or lesser degree, the capabilities of timeliness, responsiveness, flexibility, survivability, reliability, precision, and selective lethality. The following discussion centers on these major capabilities required by a global space-strike system in 2025.

Timeliness

The space-based, high-resolution surveillance and reconnaissance, high-bandwidth communications, and ultraprecise navigational systems of 2025 will make it far easier to see, move, talk, and shoot. These space systems will be fully interconnected and, because of broad-based commercialization, available to practically every nation and major organization on the planet. Key aspects of the interconnected system-of-systems will be common spacecraft bus modules, the use of industry (and probably international) standards, small and microsatellites (particularly as a means of improving technology insertion), and fully transparent tasking. The user will interact with information, not with discrete instruments. A real-time, redundant, seamless link will exist between space-based assets and assets operating within the earth's atmosphere.[1] Tailored, near-real-time information will be readily available to war fighters and their weapon systems. Every weapon system in 2025, including the global space-strike system, must be designed to make the best use of this timely information (called *in-time information* in the ***2025*** white paper entitled "In-time Information Integration System").[2] A more complete view of the near-real-time information system outlined above is available in various ***2025*** white papers dealing with surveillance and reconnaissance systems and information operations.[3]

Responsiveness

Force application missions usually begin as contingency operations, which are rapid responses to crises. A crisis may come without any notice and produce a tremendous amount of stress to disseminate information quickly and accurately. Decision makers need complete information on the developing crisis in near real time (the actual speed depends on the time available to decide and take proper action). A near-absolute assurance of connectivity is critical for a distributed information system, because if the total system does not

maintain its connections it cannot be effective—in this case, responsiveness is meaningless. The key to an effective global space-strike is, therefore, to affect a crisis or conflict decisively before it can grow out of control. The response action must occur at a rate faster than the opponent can react—"within the enemy's OODA loop" in the words of Col John Boyd.[4] In the fast-paced world of 2025, the US military's "system-of-systems," and its global space-strike system, must be more responsive than anything that exists today. The United States's OODA loops may well need to "turn" in minutes or even seconds.

Flexibility

The fog and uncertainty of war, ancient and modern, has taught military commanders to always keep their options open. At the tactical level, this means the military commander does not commit to any one course of action, nor to any fixed allotment of forces to any task, until the proper (usually the last) moment. Even then, the effective military commander must always retain the ability to switch forces from one objective to another as the conflict unfolds.[5] Surprise is an uncomfortable and unwelcome, but sadly ever-present, bedfellow for the commander.

Conflict can be characterized by the level of objective intent. The most common definition of the "spectrum of force" identifies three levels of intensity: low, medium, and high. High intensity is generally characterized by continuous engagement and an exchange of lethal blows between conventional or nuclear-capable forces with the intent of totally destroying the enemy. At the lowest end of the spectrum, the conflict involves the limited uses of force embodied in subversive, partisan, terrorist, and guerrilla tactics. Even in the slower-paced world of 1996, most military missions are at the lower and politically far more sensitive end of the spectrum. The US military must possess flexible combat systems capable of projecting force at all levels of power.

Survivability and Reliability

A system that cannot survive the outbreak of hostilities is not a useful system. A force-application system, in particular, must be "robust"—it must be available to the commander whenever it is needed. The desirable global space-strike system is one that is resistant to the enemy's attempts to render it inoperative (a *survivable* system) and that is relatively easy (in terms of cost and effort) to maintain and sustain (a *reliable* system). This is a particularly sensitive and important issue for space systems, since they are often deployed far from US support bases.

Precision and Selective Lethality

The US public recently discovered (during Operation Desert Storm) what its military has long known: the enormous value of being able to strike military targets with great *precision*. Precision reduces the total cost required to engage targets for two basic reasons: the total number of munitions assigned to a given target can be reduced once you are assured that each attempt will probably strike, and a less active agent (explosive, pyrotechnic, etc.) is required for each munition once you can select the target's most vulnerable point for engagement. More importantly, precision attacks require fewer sorties and thereby reduce the exposure of combat personnel to the danger of injury or death.

An important corollary of precision attacks involves the potential for *selective lethality*. A selectively lethal attack has two attributes: it strikes the desired target and *only* the desired target (thereby greatly reducing collateral, generally civilian, damage) and it can be "tuned" to levels of less than lethal force. A strategic nuclear bomb can be a precise combat system (fitted with an appropriate guidance system), but it cannot be a selectively lethal combat system—the nuclear bomb can only destroy its target.

An example will make the value of selective lethality clear. Consider the case of an important communications node (e.g., a

microwave tower) standing next to a children's hospital. The task at hand is to "put the communications node out of commission." This can certainly be done by successfully dropping an iron bomb directly on the tower, but only with severe risk to the nearby children's hospital. A selectively lethal combat system might accomplish the same job with greater force economy by precisely striking the tower's antenna feeds and associated electronics and overheating or melting them. The hospital is completely safe and the tower remains standing for potential postconflict use by friendly forces once the feeds and electronics have been replaced.

Notes

1. Briefing, New World Vistas Study Group, subject: Surveillance & Warning, April 1995.
2. Maj Michael J. Tiernan et al., "In-Time Information Integration System (I^3S)," ***2025*** Study (Maxwell AFB, Ala.: Air War College, 1996).
3. Lt Col Bruce W. Carmichael et al., "Strikestar ***2025***," ***2025*** Study (Maxwell AFB, Ala.: Air War College, 1996). See also CDR Clarence E. Carter, et al., "The 'Man in the Chair' - Cornerstone of Global Battlespace Dominance"; Lt Col Edward F. Murphy et al., "Information Operations: Wisdom Warfare for ***2025***"; Lt Col William Osborne et al., "Information Operations: A New Warfighting Capability"; and Maj Michael J. Tiernan et al., "In-Time Information Integration System (I^3S)" ***2025*** Study (Maxwell AFB, Ala.: Air War College, 1996.
4. John R. Boyd "A Discourse on Winning and Losing." (A collection of unpublished briefings and essays. Air University Library, Document no. M-U 43947. August 1987).
5. Air Force Manual (AFM) 1-1, *Basic Aerospace Doctrine of the United States Air Force*, vol. 2, March 1992, 283.

Chapter 3

The Integrated System-of-Systems

In this paper, the "weapon system" will be narrowly defined as the weapon itself; the platform on which it is carried; and the autonomous but interconnected surveillance, acquisition, tracking, and battle damage assessment (SAT/BDA) system needed to operate the weapon system in the desired "fire-and-forget" mode. The weapon system is a system-of-systems (weapon-platform-SAT/BDA) embedded in and interconnected with a much larger system-of-systems. Without a national global surveillance and reconnaissance system and associated intelligence system, no target will ever be found, assessed, and handed off. Without a secure, high-bandwidth global command, control, and communication (C^3) system, sensor information and command decisions cannot get where they need to go. Without a robust, distributed information system, the many types of raw sensor data can never become the fused all-source information essential to battle management. Without adequate support in the area of readiness and sustainment, a weapon system cannot be counted on to do its job. The weapon system concepts described in this white paper must be understood in this context. By 2025, no weapon system will be truly autonomous—to operate most effectively, the weapon systems of 2025 will depend on the smooth, high-speed functioning of the total US military war-making system.

The distributed nature of the system-of-systems described above can be its greatest strength or its greatest weakness. Any critical physical or intangible nodes in the distributed system could be attacked, rendering the entire system useless. The system-of-systems must be designed carefully to minimize or eliminate all critical nodes. Critical nodes that cannot be eliminated must be protected by deception, added defenses (hardening, placement within a secure environment), or redundancy. Ideally, the space weapon system itself should be so well distributed that no sensible adversary would contemplate a preemptive strike.

Only the potential weapon system concepts will be discussed in the Space Operations white paper. Some concepts for integrating the weapon system into the global information network are contained in appendix B. The information, C^3, and surveillance/reconnaissance and intelligence systems are addressed in other ***2025*** white papers.[1]

Weapon Platforms

The weapons themselves may be mounted on or fired from a space-based platform (*space-based*) or they may be mounted on platforms that traverse the space medium, such as an intercontinental ballistic missile (ICBM) or transatmospheric vehicle (TAV) (*space-borne*). Each scenario has its advantages and disadvantages, which will be detailed for each weapon system.

The space-based platform is the most responsive, because it operates immediately from the high ground of space. Possessing the unique perspective of space, space-based weapons can immediately cover a large theater of operations. This potential advantage grows as the platform's orbital altitude is increased, reaching its peak with platforms placed at geosynchronous orbit, which effectively provides access to almost half the earth's surface from a single platform. Of course, the higher the orbit, the farther the platform is from its targets. Alternatively, if the platform can be placed in low earth orbit (LEO), the range to the target can be minimized at the cost of reduced ground (and time) coverage for each platform. Given the immense volume of

near-earth space, a space-based constellation can consist of many platforms, providing reliability through redundancy. A weapon system with enough space-based platforms at the proper orbital altitude(s) can potentially ensure global, full-time coverage and provide the ability to conduct prompt and sustained operations anywhere on the planet.

As hinted above, space-based platforms are not without their limits. The inexorable laws of physics demand that low-earth-orbit platforms have orbital periods measured in tens of minutes. Global, full-time coverage for low-earth-orbiting systems will therefore require numerous platforms and/or new propulsion concepts, such as the "Hoversat," which could potentially, given enough fuel, provide loiter time by installing a jumpjet-like propulsion system on each platform.[2] Since orbits are regular and predictable, any gaps in coverage could easily be exploited by a clever adversary. Each platform must also be lifted into orbit at great cost in energy and money, unless inexpensive space lift is available by 2025. Once in orbit, each platform is automatically difficult to service and maintain. Additionally, a truly effective constellation of platforms could easily become a high-value target in plain sight for a determined adversary. If the US is the only nation possessing such a constellation, this could invite massive active or passive antisatellite (ASAT) countermeasures that would flood near-earth orbit with debris. This debris cloud would threaten the entire world's space assets. By 2025, the ramifications of such a catastrophe would be truly global, affecting every person on the planet. This potential vulnerability could be reduced by miniaturizing and stealthing space-based platforms.[3]

The class of platforms called "space-borne" platform is the most flexible, since it can potentially begin its operation under direct human control within the terrestrial environment (on land, sea, or in the air). Servicing and maintenance are less difficult for such platforms, because they are much more accessible to human technicians. Space-borne platforms can be less vulnerable, because they can be held within the confines of sovereign US territory. Their vulnerability is also reduced because they can be made highly maneuverable much more easily than a space-based system. Promising lift concepts for space-borne platforms in 2025 are described in the ***2025*** Space Lift white paper.[4]

The most familiar space-borne platform is the ICBM. American ICBMs are currently configured to deliver nuclear weapons to any location on earth within 30 minutes.[5] Given the apocalyptic nature of this weapon, nuclear-tipped ICBMs are generally regarded as the ultimate weapon of deterrence—a weapon no one really wants to use (ever). American ICBMs already exist with a circular error of probability (CEP) measured in feet.[6]

The debate on the desirability of putting man in space is a long and acrimonious one. No machine can come close to the breadth and depth of mankind's abstract reasoning ability, but it is a very costly task to develop systems to launch and sustain a manned presence in space. A *SPACECAST 2020* white paper (section H) makes the argument for a manned space-borne platform called the "Black Horse."[7] The biggest advantage of the manned TAV is that it is probably the most flexible platform yet proposed for space operations simply because it is under the continuous control of a human. Given an appropriate design, the manned TAV could be quickly reconfigured to deliver special operations teams, high-value equipment and supplies, or a wide variety of munitions (in much the same fashion as a high-speed bomber).[8] Most important of all, the TAV can put a few well-trained people at the site of a developing conflict anywhere on earth within 60 minutes from launch.[9]

The most important disadvantage of space-borne platforms is their relative lack of responsiveness. A TAV can reach anywhere on earth within 40 minutes once it has reached orbit, but this cannot compare with

a speed-of-light attack from a directed-energy weapon in orbit above a target. If a spaceborne platform is not already hovering "near station," this single disadvantage may be fatal in an era when response times have improved to minutes or even seconds.

Weapon Classes

The potential space-strike weapons can be broadly grouped into four categories: directed energy, projectile, space sortie, and information. Information "weapons" are discussed in white papers prepared by other ***2025*** teams.[10] The rest of the weapon systems will be described in terms of their capabilities and shortfalls, and countermeasures for each system will be discussed. Finally, each system is evaluated in light of timeliness, responsiveness, flexibility, precision, survivability, reliability, and selective lethality (desired capabilities described in chapter 2). The final result will be selection of a credible space-force application system-of-systems.

Directed-Energy Weapons—Incoherent Light

Unfiltered by the atmosphere, the sun provides an enormous flux of natural (incoherent) light in near-earth orbit. Our best measurements of this flux put the available power density at 0.1395 W/cm^2.[11] Currently, this vast power source is tapped with solar arrays to power satellites. It is conceivable that large focusing mirrors equipped with pointing and tracking and maneuvering systems could be placed in orbit to intercept and redirect solar energy onto the battlefield.[12] Single, very large mirrors (on the order of kilometers in diameter) or large arrays of smaller mirrors working in concert would be needed to make this concept useful. Even in LEO orbit, these mirrors would need pointing and tracking accuracies of 10 to 100 nanoradians to qualify as precision-aimed weapons.

Optical systems (primarily collecting apertures) currently under study have been limited artificially to a size of four meters for potential launch on the space shuttle.[13] The optical substrates are made from ultralow-expansion, rigid glasses such as Zerodur[R] that are made lightweight with acid-etching techniques.[14] Larger, still lightweight structures could potentially be made from advanced aerogel materials, advanced ceramics (such as SiC), engineered composites, structurally supported optically coated plastics, suspended or spun-reflective liquids (a liquid mirror), or inflatable mirrors (reflective films on an inflatable substrate).[15] All these approaches have been demonstrated at the earth's surface with structures measured in feet or at most a few meters.[16]

Capabilities

The most likely incoherent-light weapon would consist of an orbiting array of mirrors in the 10- to 100-meter class. With the proper constellation, the orbiting mirrors could intercept and redirect sunlight onto the earth's surface. The simplest use of the system would be to provide battlefield illumination on demand. Depending on the area illuminated, useful illumination could be provided by one to 100 mirrors operating in concert. By focusing the light from many mirrors onto a single spot or series of spots, battlefield temperature could also be raised (a potential form of weather modification—see the ***2025*** white paper "Weather as a Force Multiplier") and optical sensors (including human eyes) could be temporarily blinded.[17] Emergency electrical power could be "beamed" to lightweight solar panels erected to intercept the redirected sunlight. To achieve more permanent effects, such as melting, as many as 100 mirrors might need to point and track on a single hardened target for a period ranging from several tens to hundreds of seconds. Spotlight beams from a few mirrors could also be used to aid search and rescue or special operations missions at night. Incoherent-light weapon systems are limited in the rate at which they cause permanent damage by the fact that

incoherent light, unlike coherent (laser) light, cannot be focused onto extremely small spots.

Countermeasures

Incoherent light is difficult to focus; easy to block with broadband reflective, scattering, or absorptive barriers (such as aerosol clouds); and can be decoupled from target surfaces with reflective coatings. The last two countermeasures can be defeated, however. Reflective coatings tend to degrade naturally, especially in the battlefield environment, and they can be deliberately attacked with abrading materials (sand) or absorptive liquids (paints/dyes). Blocking barriers can be attacked and eliminated by cooperative land, sea, or air forces. In particular, blocking clouds of aerosols (e.g., smoke) can be rapidly eliminated with heavy liquid sprays. A clever adversary can also delay damage to his assets by spreading the absorbed heat through rotating some targets (such as missiles) or by insulating targets with inexpensive materials like cork.[18]

Evaluation

The biggest advantage of an incoherent light weapon (if the technology could be adequately developed) is the endlessly available power supply. The range of lethality is also attractive assuming the precision pointing and tracking problems could be conquered. However, the flexibility and survivability of mirrors that may need to be hundreds of meters or even kilometers in size negates this as a viable weapon system. Furthermore, if the constellation were placed in a LEO for better accuracy, sustainment, and reliability, there would have to be many of these very large mirrors just to ensure good timeliness and responsiveness; this is neither practical nor cost-effective.

DEW—Coherent Light (Lasers)

Lasers can be built as either continuous wave (CW) or pulsed devices.[19] CW laser effects are generally described in terms of power density on target in W/m^2; pulsed laser effects are described in terms of energy density on target in J/m^2.[20] Although significant advances in this technology have been made by both Ballistic Missile Defense Office (SDIO/BMDO) and the USAF Phillips Laboratory Airborne Laser (ABL) organizations, laser technology still needs further development.[21] To date, ground-based chemical lasers have been built in the megawatt class (the ALPHA laser).[22] Phillips Laboratory is also developing a hundred-kilowatt-class shortwave CW chemical laser (SWCL) based on the oxygen-iodine chemical system.[23] Weapons-class pulsed lasers have also been built, but primarily for effects and materials research.[24]

For the space-earth geometry (see fig. 3-1), multimegawatt power is required for a CW weapons laser and hundreds to thousands of joules of energy per pulse is required for a pulsed weapons laser (depends on pulse length and pulse repetition frequency).[25] Total power or energy requirements are correspondingly higher for the earth-space-earth geometry. Constellations employing only a few space platforms (e.g., laser stations for the space-earth geometry, laser mirrors for the earth-space-earth geometry) would have to compensate for long slant ranges and correspondingly higher-atmospheric distortion by using even more powerful beams.[26] Lasers

Figure 3-1. A Notional Space-Based Laser

are not all-weather systems. The laser wavelength, and therefore the laser gain medium and optics train, must be carefully chosen to permit good atmospheric propagation. Clouds absorb and scatter laser light, removing power from the beam and distorting the beam's "footprint."

The size of the optics necessary to point and focus a laser beam depends on the frequency of the laser and the range to the target. For visible and near-infrared lasers, the frequencies under study for use at long range, optics in the four- to 20-meter diameter should suffice for a system in low earth orbit.[27] For a brief review of research trends in large optics, see the earlier discussion on incoherent-light weapons.

To achieve the status of a precision-aimed weapon, laser weapon systems will require pointing and tracking accuracies in the 10 to 100 nanoradian range for systems in low earth orbit.[28] The SDIO/BMDO acquisition, tracking, pointing, and fire control program has already demonstrated a pointing stability to "below the program goal of less than 100 nanoradians."[29] It has, however, not yet been proven that large structures in earth orbit can be stabilized to these levels. This is a challenge of particular importance for a distributed laser weapon system consisting of an earth-based laser and a constellation of space-based mirrors. In this scenario, the laser beam must be relayed by several space mirrors before it reaches some targets.

Adaptive optics techniques such as the Guide Star System have been developed to correct atmospheric distortions to low-power laser beams projected from earth to space and back again.[30] Adaptive optics systems developed to date depend primarily on deformable mirrors—mirrors with small actuators that change the mirror's shape to precompensate the beam and correct anticipated or premeasured distortions. Further advances will be required in this technology, both in terms of bandwidth and number/size of actuators, to make this technology work for weapons-class lasers. Current advances in microelectromechanical machines and nanotechnology show great promise in this area.[31] The bandwidth problem on the processing side will probably "handle itself," given the current rate of growth in semiconductor technology and continued commercial/government interest in optical processing techniques.[32] Advances in high-speed (10 Gbits/sec and up) laser communication systems are also likely to yield solutions of interest to the laser weapon designer.[33]

Capabilities

Lasers are extremely flexible weapons, producing effects that cover the full "spectrum of force." At low power, laser beams can be used as battlefield illumination devices, but with a potential added benefit over incoherent illumination. Using an invisible laser beam (near infrared) at a specifically chosen wavelength and special tuned vision devices similar to night-vision goggles, one could render the battlefield visible only to friendly troops.[34] At low to medium power, laser beams can be used to designate targets from space, blind sensors in the laser's optical band, ignite exposed flammable objects, raise the temperature in localized regions (possible weather modification effect—see the ***2025*** white paper "Weather as a Force Multiplier"),[35] perform as an emergency high-bandwidth laser communication system, and serve as a laser probe for active remote-sensing systems.[36] At slightly higher powers, the enhanced heating produced by the laser can be used to upset sensitive electronics (temporarily or permanently), damage sensor and antenna arrays, ignite some containerized flammable and explosive materials, and sever exposed power and communications lines. The full power beam can melt or vaporize virtually any target, given enough exposure time. With precise targeting information (accuracy of inches) and beam pointing and tracking stability of 10 to 100 nanoradians, a full-power beam can successfully attack ground or airborne targets by melting or cracking cockpit canopies, burning through control cables,

exploding fuel tanks, melting or burning sensor assemblies and antenna arrays, exploding or melting munitions pods, destroying ground communications and power grids, and melting or burning a large variety of strategic targets (e.g., dams, industrial and defense facilities, and munitions factories)—all in a fraction of a second.

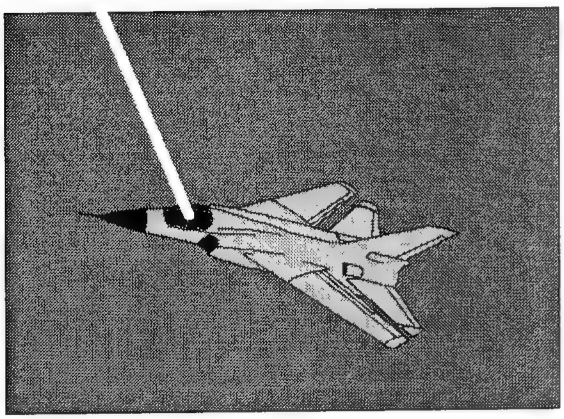


Figure 3-2. Precision Laser Strike on Aircraft

Pulsed lasers can also produce additional effects based on their ability to deliver rapidly a large amount of energy in a small amount of time. Weapons-class pulsed lasers can vaporize target surfaces so rapidly that an effect very like a rocket firing occurs. In essence, the target experiences a shove or impulse with every laser pulse. If a strong enough impulse is delivered, the laser can discriminate between valid air- or space-borne targets and lightweight decoys (although the details of this process are very difficult to satisfy).[37] If the impulse can be delivered at an object's resonant frequency, cracking and breaking will occur. Similarly, a pulsed laser trained on an object at the proper pulse-repetition frequency can stimulate infrasound vibrations, a potential form of nonlethal force projection that disrupts a target with penetrating, low-frequency oscillations.

Perhaps more significantly, the large space-based mirrors of a distributed laser weapon system (laser is ground based) can also be used as a high-quality, passive remote-sensing system.[38] By training ground-based, high-power optical telescopes on the mirrors, America's "eyes" can literally be carried to every corner of the earth. Cued by a broader area search, this capability could be the primary surveillance, battle damage assessment, and targeting system for the laser space strike weapon or a valuable adjunct to America's existing national technical means. With a large constellation of space-based mirrors in LEO, America's opponents could literally never be sure when they are being watched, closing the existing coverage gaps. Rather than depending on a few large, expensive assets that will inevitably become tempting targets, we can protect our surveillance and reconnaissance capability by increasing the number of "eyes" in orbit.

A weapons-class laser is useful only so long as it has fuel. This is a particular problem for a space-based laser, since it can be expensive to lift large quantities of fuel into orbit. This problem could be mitigated by using solid-state or diode laser systems that can be configured to operate on electrical power.[39] Such systems are also attractive because of their relatively high efficiency. Diode laser systems have been built with electrical efficiencies as high as 50 percent at room temperature and cooled diodes have demonstrated efficiencies of 90+ percent.[40] The most powerful contemporary diode laser arrays are still low-power systems (1–100 watts), although the technology appears to be scalable.[41] Enormously powerful pulsed glass laser systems have been built as elements of the Department of Energy inertial confinement fusion program, but these systems are huge, inefficient, and quite fragile.[42] Clearly, further technology work is required to make these systems deployable.

Atmospheric interactions are another challenge for weapons-class lasers. Aside from the obvious scattering and absorption problems, high-power CW lasers are known to cause "thermal blooming" (e.g., a severe

defocusing of the beam) and "beam steering" (unintended shifts in beam direction) when they pass through the atmosphere.[43] Pulsed high-power lasers, with their attendant powerful electric fields, can stimulate nonlinear optical effects such as "harmonic generation" (the inadvertent generation of other colors of light) that rob power from the main beam and make it difficult to focus the laser on the target.[44] Laser beams of higher frequency are more easily focused on the target, requiring smaller control optics and mirrors. Unfortunately, high-frequency lasers are inherently more difficult to develop, usually requiring dangerous exotic fuels and exhibiting much lower efficiencies.[45] High-frequency lasers, particularly those above the green region of the spectrum, also scatter very strongly in the atmosphere and are increasingly subject to the nonlinear optical effects previously discussed.

Current weapons-class lasers all produce beams in the near infrared (short-wave infrared or SWIR). These frequencies are strongly affected by clouds and suspended particles, and cannot always be depended on to engage targets below the cloud tops at about 30,000 feet.[46]

Countermeasures

Lasers are subject to the same basic countermeasures as incoherent light weapons and can be aided by the counter-countermeasures outlined above. An additional phenomenon known as the laser supported combustion (LSC) wave can occur when a high-power laser beam strikes a target surface.[47] As the laser vaporizes surface material from the target, the hot gas can absorb even more energy from the laser beam. If enough energy is present on a short enough timescale, the hot gas is rapidly ionized, producing a hot, dense plasma. The plasma absorbs all the incident energy, essentially shielding the target surface from the direct effect of the beam. This phenomenon is generally a problem for high-power pulsed lasers and represents the upper limit to the amount of laser power one should generally attempt to put on target. At even higher incident powers, the LSC develops into a detonation wave or LSD that swiftly travels back up the laser beam, further decoupling the laser from the target.

Evaluation

The coherent light laser is an extremely attractive space-strike weapon for several reasons. It is highly responsive and timely (e.g., could strike within seconds after a decision is made to take action), it has already demonstrated high-precision capability (especially in recent ABL and SDIO/BMDO tests), and it has inherently high flexibility and selective lethality (from "lighting the battlefield" to temporarily disturbing sensors and electronics to melting or burning large or small targets). Additionally, the ground-based lasers could be relayed to or independently pointed at the space systems of aggressor nations (or organizations), serving as an important US space-control asset as needed. When not needed as a force-application or space-control weapon system, the space-based mirrors can form the basis for a very effective, survivable space-based global surveillance and reconnaissance system.

In a LEO constellation, a 20-meter mirror is certainly not as daunting as a kilometer-sized one, but it is still awkwardly large and therefore expensive and less survivable. In fact, each space-based mirror would need a covering until it is used, lest it be damaged by simple antisatellite attacks or by space debris and contamination (altering the surface and rendering the mirror useless for relaying high-power laser beams). Reliability is also a concern due to the large amounts of power required by the ground-based laser and the lamentable effect of weather (clouds) on the operational availability of the system. However, a distributed laser space-strike system with ground-based lasers could certainly be maintained and even upgraded much more easily than a completely space-based system, thereby increasing the overall reliability. In sum,

ground-based CW lasers coupled to space-based mirrors seem a highly effective and feasible option for a space-strike weapon system in 2025.

Neutral Particle Beam

A neutral particle beam (NPB) weapon produces a beam of near-light-speed, neutral atomic particles by subjecting hydrogen or deuterium gas to an enormous electrical charge.[48] The electrical charge produces negatively charged ions that are accelerated through a long vacuum tunnel by an electrical potential in the hundreds-of-megavolt range. At the end of the tunnel, electrons are stripped from the negative ions, forming the high-speed-neutral atomic particles that are the neutral particle beam. The NPB delivers its kinetic energy directly into the atomic and subatomic structure of the target, literally heating the target from deep within.[49] Charged particle beams (CPB) can be produced in a similar fashion, but they are easily deflected by the earth's magnetic field and their strong electrical charge causes the CPB to diffuse and break apart uncontrollably. Weapons-class NPBs require energies in the hundreds of millions of electron volts and beam powers in the tens of megawatts.[50] Modern devices have not yet reached this level.[51]

Particle beams are an outgrowth of conventional atomic accelerator technology. Weapons-class particle beams require millions of volts of electrical potential, powerful magnetic fields for beam direction, and long accelerating tunnels. Current technology accelerator devices with these capabilities weigh in the hundreds of tons and require enormous power sources to operate.[52] Composed of neutral atoms, NPBs proceed in a straight line once they have been accelerated and magnetically pointed just before neutralization in the accelerator. An invisible beam of neutrally charged atoms is also remarkably difficult to sense, complicating the problem of beam control and direction.[53]

Capabilities

Like lasers, NPBs are essentially light-speed weapons. More difficult to control and point than the light weapon, the NPB is strictly a line-of-sight device (cannot be redirected). Moreover, an NPB would be difficult and expensive to place in orbit. Many tons of material must be lifted and a complex device must be constructed under free-fall conditions. This means the power supply, accelerator, beam line, magnetic focusing and pointing device, stripper, maneuvering system, and SAT/BDA system must all be located on a large platform on orbit. A useful constellation of NPB systems in LOW must contain many platforms (dozens) to avoid gaps in coverage. A constellation in higher orbit would require fewer platforms, but it would be correspondingly more difficult to control the beam and put it on target.

In addition, the NPB is strongly affected by passage through the atmosphere, attenuating and diffusing as it passes through dense gas or suspended aerosols (e.g., clouds, and dust).[54] A space-based NPB is therefore most useful against high-flying airborne or spaceborne targets. At relatively low powers, the penetrating beam can enter platforms and payloads, producing considerable heat and uncontrollable ionization. Thus, the NPB is useful at the low end of the spectrum of force, producing circuit disruption without necessarily permanently damaging the target system. At higher powers, the NPB most easily damages and destroys sensitive electronics, although it is fully capable of melting solid metals and igniting fuel and explosives. Like the laser, the NPB is inherently a precision-aimed weapon. To be most effective, an NPB weapon should therefore receive very precise targeting information (inches) and must have a pointing and tracking system with extreme stability (10 to 100 nanoradians). With this level of support, the NPB would be able to quickly disable targets by centering its effect on vulnerable points

(e.g., fuel tanks, control cables, guidance and control electronics, etc.).

Like the pulsed-laser weapon, the NPB can be used to discriminate against decoys in a ballistic missile defense scenario (e.g., a very difficult, but theoretically possible mission). When the beam penetrates a target, the target's atomic and subatomic structure produce characteristic emissions that could be used to determine the target's mass or assess the extent of damage to the target. The SDIO/BMDO has already researched and demonstrated detector modules based on proportional counter and scintillating fiber-optics technologies that are reportedly scalable to weapon-level specifications.[55]

Countermeasures

Rapid maneuvers and dense shields are the best countermeasures for an NPB. If the beam can be generated successfully and pointed at the target, it is difficult to defend against. Since the beam deposits its energy deep into the target's atomic structure, the primary weapon effect is penetrating heat deposited so rapidly it causes great damage.

Evaluation

It does not appear feasible to develop an NPB weapon system as a space-based system even by 2025 due to the weight, size, power, and inherent complexity of the NPB. Also, due to the line-of-sight restrictions, the timeliness and responsiveness would be low to moderate as the weapon "waited" for the target to move within view. The flexibility and selective lethality of the NPB is also moderate in that it can range from temporary to permanent damage. Precision is excellent in theory, but questionable in use due to earth's magnetic field and countermeasures. Since the beam is strongly affected by passage through the atmosphere, ground- or sea-based targets probably could not be targeted. Finally, the reliability of such a complex, easily affected weapon is moderate at best. The NPB weapon system does not appear to be practical in 2025.

Electromagnetic Pulse

An electromagnetic pulse (EMP) is a sudden, high-intensity burst of broad-band electromagnetic radiation. The range of electromagnetic frequencies present depends on the source of the EMP. The high-altitude airburst of a nuclear weapon produces an intense EMP which, because of the relatively long duration of the explosion, contains strong low-frequency components (below 100 MHz).[56] Conventional EMP devices built with explosively driven, high-power microwave technology produce a less intense, very short (nanoseconds) burst composed primarily of microwave frequencies (100 MHz–100 Ghz).[57] The range of the EMP effect depends on the strength of the source, as the initial electromagnetic shock wave propagates away from its source with a continuously decreasing intensity.[58]

The gamma radiation produced by a fission or fusion bomb interacts with the atmosphere, creating a large region of positive and negative charges by stripping electrons from atmospheric gasses.[59] The motion of these charges creates the EMP. The pulse enters all unshielded circuits within range, causing damage ranging from circuit malfunction and memory loss to overheating and melting.[60]

Militarily useful EMP can also be created by mating a compact pulsed power source (gigawatt range), an electrical energy converter, and a high-power microwave device such as the "vircator" (virtual cathode oscillator).[61] An advantage of a conventional EMP device is that it can be triggered in a shorter amount of time, thereby putting more output energy into the higher microwave frequencies (above 100 MHz). Since modern electronics operate primarily in these microwave bands, the EMP produced by conventional devices is potentially very effective in shutting down electronics. Explosively pumped EMP devices such as the vircator have another

advantage: it is possible to design them to focus their EMP in a particular direction. Even a focused EMP effect produced by a conventional device will probably have a lethal radius measured only in hundreds to thousands of meters, depending upon the strength of the power source and atmospheric absorption (particularly at frequencies above 20 Ghz).[62]

Finally, the USAF Phillips Laboratory has produced compact plasma toroids with energies in the range of 10 kilojoules.[63] Directed at solid targets, the plasma toroids induce rapid heating at the surface, producing extreme mechanical and thermal shock as well as a burst of X rays.[64] The X-ray burst can also be used to generate EMP. While theory predicts the toroids will be rapidly dissipated by the atmosphere, there may well be a method of delivering high-energy plasmas to the vicinity of a target that does not involve long paths in air.

Capabilities

The few experiments with nuclear bursts in space have revealed that the size of the nuclear EMP effect is related less to the yield of the bomb than to the altitude of the burst. A 100-kiloton burst at an altitude of 60 miles would create damaging EMP over an area equal to half the United States. At 300 miles, the same burst would create EMP over an area equal to the entire US plus most of Mexico and Canada. The gamma burst from a (purely theoretical) microyield nuclear device might be used to create a more manageable EMP effect.[65]

Electrical devices exposed to an EMP burst experience effects ranging from temporary electronic disruption at the outer edge to destructive electrical overvoltages near the center. Modern semiconductor devices, particularly those based on MOS (metal oxide semiconductor) technology such as commercial computers, are easily damaged by these high-voltage transients.[66] Long ground lines, such as electrical transmission wires, act as enormous antennas for the EMP burst.[67] Power transmission and communication grids are therefore extremely vulnerable and will probably be destroyed by the burst. Any system containing semiconductor electronics, including airborne platforms, would be shut down or burned out by the burst unless it was completely protected with heavy, expensive electrical and magnetic shields, well-designed electrical filters, and careful grounding. An extremely effective area weapon, the EMP produced by a nuclear airburst would undoubtedly produce severe damage to the civilian infrastructure.

A more flexible form of EMP weapon system would employ either a microyield nuclear weapon (yield below two kilotons), a conventional explosively driven EMP device or plasma technology to produce the EMP.[68] Microyield nuclear weapons or conventional EMP devices could be delivered to the vicinity of the target as a bomb (perhaps by a TAV) or as the warhead of a missile. Given the unpredictable but damaging effect of EMP on electrical and electronic equipment, these EMP "explosions" are best used against enemy platforms and facilities that depend on sophisticated electronics, particularly the enemy's command, control, and communications system (strategic target) and the enemy's air defenses (operational target).[69] Missiles equipped with EMP warheads are also effective weapons in the fight for air superiority, since modern high-performance fighter aircraft depend heavily on sophisticated, and therefore vulnerable, electronics.

The main difficulty with the nuclear EMP effect is its indiscriminate nature. The pulse travels in every direction and covers large areas of the planet, potentially damaging friendly assets just as greatly as those of the enemy. Another impediment to the use of nuclear-driven EMP weapons is the worldwide aversion to nuclear weapons, particularly nuclear weapons on orbit. Once a nuclear bomb explodes in space, the charged particles produced can easily be trapped in the earth's Van Allen radiation

belts. This would greatly increase the radiation exposure for any satellite passing near the radiation belts, disrupting or destroying poorly shielded satellites. The charged particles would remain in the radiation belts for an extended period of time, denying the use of space to friend and foe alike.[70]

Countermeasures

Nuclear-driven EMP is omnidirectional, spraying large areas with damaging, broadband electromagnetic radiation. EMP created using more conventional technologies is characterized by directionality, relatively short range, and electromagnetic output centered in the damaging microwave frequencies. Arriving at light speed, the broadband nature of EMP makes it extremely difficult and expensive to defend against.[71] Thus, the primary countermeasure for EMP weapons is electromagnetic shielding. Shielding must be provided separately against the electric and magnetic field components of EMP and it must take into account the broadband nature of the pulse. Since a great range of frequencies are present in EMP, the designer must shield against low, medium, and high frequencies. The designer must also install protective electrical filters wherever an electrically conductive channel enters electrical systems (e.g., power cables, transmission lines, antenna inputs, etc.). Since filters perform differently at different electrical frequencies, this is a difficult task.[72] A single mistake in grounding, filter design, or shielding geometry is enough to provide entry for damaging amounts of EMP, especially in high-speed computer circuitry. This suggests the appropriate counter-countermeasure. The antagonist need only break a few electrical grounds, shift the output spectrum of his EMP attack, or penetrate the shielding at a few critical points to render this countermeasure worthless. Once the energy from an EMP effect has entered a region's power grid, communications grid, or computer grid, the entire network can be disrupted for a period of time or even destroyed.

Evaluation

Due to its indiscriminate nature, nuclear-driven EMP is only appropriate in total war scenarios (zero flexibility). The conventional EMP weapon, on the other hand, shows more flexibility in that it could be directional and its effects could be localized. Both forms of EMP weapons are at least moderate in their timeliness and responsiveness, since an EMP "bomb" could potentially reach its target within 30 minutes after launch (by means of a delivery vehicle similar to the modern ICBM). The precision of the EMP weapon is relatively low—it is generally useful only for area targets (e.g., enemy towns, large facilities, or a squadron of enemy aircraft). The survivability and reliability of EMP weapons are moderate to high, particularly if the weapons themselves are ground based (as the payload of an ICBM or surface launched ballistic missile [SLBM]). Finally, and most unfortunately, the selective lethality of EMP weapons is low. The effect of an EMP burst on any given electrical system is highly unpredictable, since it depends in great detail on the precise geometry of the engagement, the exact design of the electrical system under attack, and even the current state of the atmosphere. In sum, the conventional EMP weapon has very interesting possibilities as a potential future weapon. However, the currently unpredictable lethality, limited flexibility, and questionable precision make it unattractive as the primary component of a space-strike weapon system in 2025.

High-Power Microwave

A high-power microwave (HPMW) device also employs electromagnetic radiation as its weapon effect. Not as powerful as nuclear-driven EMP weapons, HPMW weapons create a narrower band of microwave electromagnetic radiation by coupling fast,

high-energy pulsed power supplies to specially designed microwave antenna arrays. Microwave frequencies (tens of megahertz to tens of gigahertz) are chosen for two reasons: the atmosphere is generally transparent to microwave radiation (all-weather capability) and modern electronics are particularly vulnerable to these frequencies. Unlike most EMP weapons, HPMW weapons produce beams defined by the shape and character of their microwave antenna array. HPMW beams are broader than those produced by NPBs and lasers, and this space-strike weapon system does not require extreme pointing and tracking accuracies (100 nanoradian stability and one-meter target accuracy are adequate). HPMW weapons can be trained on a target for an extended period of time, provided the power supply and HPMW circuitry can withstand the internal currents. As a rough point of comparison, HPMW systems produce 100 to 1,000 times the output power of modern electronic warfare (EW) systems.[73]

Capabilities

This light speed weapon can be understood as a microwave "floodlight" that bathes its targets in microwave radiation. More directional and controllable than EMP, the general effect of this weapon on electrical systems is well described in the section on EMP. Unlike conventional EW techniques, the effects of a HPMW weapon system usually persist long after the "floodlight" is turned off (depends on power level employed).[74]

Laboratory experiments have revealed that modern commercial electronic devices can be disrupted when they receive microwave radiation at levels as low as microwatts/cm^2 to milliwatts/cm^2.[75] The more sensitive the circuit, the more vulnerable it is. While many electronic devices can be shielded using the same techniques outlined in the section on EMP weapons, most sensors and high-gain antennas cannot be shielded without preventing them from performing their primary functions.

HPMW weapons are inherently limited by the fundamental laws governing electromagnetic radiation. A space-based HPMW weapon must have an antenna or array of phased antennas with an area measured in acres to point and focus its beam properly on terrestrial targets. The resources necessary to construct such huge structures could be expensive to lift into orbit, and difficult to assemble in the free-fall environment. Like the NPB, the HPMW weapon is a line-of-sight device that must "see" its target before it can fire.

The level of pulsed electrical power required to produce weapon-level microwave fluxes is now becoming available (for ground-based systems). Compact, scalable laboratory sources of narrow-band, high-power microwaves have been demonstrated that can produce gigawatts of power for 10 to a few hundred nanoseconds. Ultrawideband microwave sources are less well developed, but research in this area appears promising.[76] A HPMW weapon should, however, be able to temporarily disrupt circuits and jam microwave communications at low-power levels.

A space-strike HPMW system would consist of a constellation of satellites with very large antennas or arrays of antennas. The farther out in space the constellation resides, the fewer the number of satellites required. However, there is a corresponding increased requirement for more power and larger antennas. Another possibility is to overlap "spot" beams from many smaller HPMW satellites on each target, gaining the benefit of high power on centroid (but a very much larger combined spot) at the cost of satellite proliferation. A useful distributed HPMW weapon system of this type might resemble the Iridium or Teledesic constellations of LEO communication satellites (many tens to hundreds of satellites; however, the HPMWs would not be small satellites).

At low powers, the HPMW weapon system is fully capable of jamming communications

when pointed at the opponent's receiving stations or platforms, in addition to its obvious uses against an enemy's electrical and electronic systems at higher power levels. Since water molecules are also known to absorb certain bands of microwave frequencies, it is also possible that a properly designed HPMW weapon system could be used to modify terrestrial weather.

Countermeasures

Modern advances in microelectromechanical devices and nanotechnology could eventually result in devices and sensors so small that they are only a tiny fraction of a microwave wavelength in size. Minute devices, if small enough, could be immune to HPMW weapons simply because microwave frequencies cannot couple enough energy into them to cause damage. Advances in optical computing and photonic communications could also be a useful countermeasure. Optical devices are inherently immune to microwave radiation, although the sections of optical circuits where light is converted back into current would still have to be shielded. The countercountermeasures outlined in the section on EMP weapons are also useful for HPMW weapons.

Evaluation

The all-weather characteristics of the HPMW make it very attractive for a 2025 weapon. With a space-based version, this light-speed weapon would be high in timeliness and responsiveness. However, the flexibility and precision characteristics are similar to the nuclear EMP device—low. In addition, like the NPB, it is limited by line-of-sight restrictions. Moreover, its requirement for acres of antenna for each of the satellites required for a LEO constellation simply make it impractical. Finally, selective lethality is, like EMP, somewhat unpredictable. And by 2025, if nanotechnology is perfected and incorporated widely into electronic systems, this could negate much of the effects of a HPMW. Thus, the HPMW weapon system is not deemed suitable for space-force application in 2025.

Illusion

Sun Tzu said, "All war is based on deception."[77] Military commanders have always sought to hide their intentions, capabilities, and forces from their opponents. The most prominent modern example of deceptive techniques is stealth technology, which seeks to hide platforms from sensors by reducing the various sensor cross sections (i.e., radar, optical, infrared, acoustic, etc.). Modern advances in holographic technologies suggest another possibility: weapons that project false images to deceive the opponent.[78]

Holograms are produced by scattering laser light or intense bursts of white light off objects and forming three-dimensional interference patterns. The information contained in the interference pattern is stored in a distributed form within solid emulsions or crystals for later projection with a source of light similar to that used to produce the interference pattern.[79]

Capabilities

Full-color holograms can only be produced with white light sources, and even the best modern white-light holograms are imperfect.[80] It is certainly possible to make holograms of troop concentrations, military platforms, or other useful objects, although the larger the scene the more difficult it is to produce the proper conditions to create a convincing hologram. No credible approach has been suggested for projecting holograms over long distances under real-world conditions, although the Massachusetts Institute of Technology's Media Lab believes holographic color projection may be possible within 10 years.[81] Holographic and other, less high-technology forms of illusion may became a potent tool in the hands of the information warriors (see the ***2025*** information warfare white papers).[82]

Countermeasures

The best countermeasure for holographic illusions is the use of multiple sensor types. The most convincing optical illusion could easily be exposed by its lack of an appropriate infrared or radar signature. The likely proliferation of sensors and sensor types on the battlefield of 2025 makes the use of merely optical illusions a temporary expedient, at best. Nevertheless, considerable confusion could be created, at least temporarily, by projecting false infrared signatures (platform exhausts) or radar signatures (missiles) or by concealing one type of platform within the illusion of another type (or of nothing at all—a form of camouflage).

Evaluation

Illusion weapons are and will probably continue to be too limited in the 2025 time frame. The flexibility is low, precision uncertain, survivability and reliability are low, and the selective lethality involves deception only. With the proliferation of sensor devices projected for 2025, the attempt at deception would likely be detected so quickly as to have little effect.

Projectile Weapons

Projectile weapons are most easily described by dividing them into two classes: ballistic missiles (BM) and kinetic-energy weapons (KEW). The ballistic missile is commonly used as a high-speed means of delivering a weapons payload over long distances with adequate precision to strategic targets. The kinetic-energy weapon works on the simple concept of delivering a mass at extremely high velocities to the target. The basic kill mechanism for a KEW is its kinetic energy (KE) as calculated by the simple formula KE = 0.5 x (total mass) x $(\text{velocity})^2$.[83] In general, the more kinetic energy delivered, the more damage done to the target. This places a premium on achieving high speeds, since the kinetic energy depends on the square of the weapon's velocity.

Projectile Weapons—Ballistic Missiles

Ballistic missiles are popular with many countries today due to their capability to deliver a payload to the country next door or to a country on the other side of the world. They can even be used to deliver satellites into space (Atlas and Titan IVs are popular in the US). Their fuel can be liquid or solid and they are fairly reliable. The guidance systems can use global positioning system (GPS) receivers or inertial navigation systems and US systems are known to be very precise (measured in feet). Finally there is a wide range of possible payloads: nuclear warheads, chemical/biological devices, submunitions, solid masses, satellites, nonlethal payloads like foams or a debilitating gas, and so forth.

Capabilities

The modern ICBM/SLBMs are strategic weapons of deterrence. As such, they inevitably carry devastating nuclear payloads. However, this is not the only possibility. With a CEP already measured in feet, ballistic missiles (theater or intercontinental) could be configured to carry more conventional payloads.[84] The simplest useful payload is a solid tip (essentially a ton of cement in the nose). Few fixed targets could resist the sheer momentum of several tons of material delivered precisely at high speed from space. A simple variation on this approach replaces the solid tip with a high-explosive charge. Equipped with the proper high speed fuse and possibly a shaped charge, this weapon could be very effective against many hardened facilities, especially shallowly buried bunkers or tunnels.

A ballistic missile could also be configured to carry a variety of submunitions. A reentry vehicle could be equipped with many long, dense rods that, when properly dispensed at high speed, would be excellent bunker busters. Alternatively, the reentry vehicle could contain hundreds or thousands of metal or ceramic flechettes (darts) designed

to shred area targets such as enemy bases, weapon-making facilities, or threatening troop concentrations. The conventional EMP bombs described previously could be delivered to enemy C^4I, air defense, and industrial facilities, disrupting or damaging all electronics without necessarily exacting a high cost in lives. Finally, a ballistic missile could be configured to deliver some form of nonlethal payload such as hardening foam, irritating gas, or foul smelling liquid.[85]

As regional wars in the Middle East have recently demonstrated, it is also possible to deliver chemical and biological weapons (CBW) with ballistic missiles. These unsettling, but potentially very effective area weapons share several disadvantages with nuclear weapons. CBWs are condemned by most nations as cruel and unusual weapons. Preemptive use of these weapons certainly invites worldwide condemnation. CBW devices are also uncontrollable once released—the areas affected are denied to friend and foe. Worse yet, chemical and biological agents are spread uncontrollably by environmental and natural vectors (e.g., insects and animals). In their current form, CBW devices are decidedly not precision weapons.

Countermeasures

Ballistic missiles, whether theater or strategic in nature, are a particularly high-value target for space-strike laser weapon systems. Ballistic missiles spend tens to hundreds of seconds in the boost phase (theater ballistic missile [TBM] versus ICBM) followed by tens of seconds to tens of minutes in the postboost phase.[86] These missiles are easily detected by their plumes only during boost phase, the shortest phase of their trajectory. During this brief interval of vulnerability, a light-speed kill by a space-based or space-borne laser weapon system can settle the problem before it has the opportunity to deploy multiple independently targeted reentry vehicles (MIRV). In general, ballistic missile countermeasures have been addressed in great detail by the Ballistic Missile Defense Organization. The solutions range from direct interception by high-speed rockets and missiles to airborne and ground-based high-energy laser strikes.[87]

The appropriate countercountermeasures are obvious. Stealthy reentry vehicles could be built that elude ground- and space-based sensors, although the designer would be forced to address optical, infrared, and multi-frequency radar problems simultaneously. Alternatively, very small, very agile reentry vehicles that greatly complicate the problem of terminal defense could be designed.

Evaluation

Most of these missile-delivered weapons could be built today. All of the essential technologies, including precise delivery, are already available. The flexibility of a ballistic missile system is moderate and precision and reliability are good, but selective lethality is limited, and survivability of such a system may be tenuous in 2025. Because of these limits on selective lethality and potential survivability problems, the ballistic missile will probably not be suitable for space force application in 2025.

Projectile Weapons—Kinetic Energy

This type of projectile weapon is closely related to the solid-tipped ballistic missile. Kinetic-energy weapons come in two classes related to their velocity—the Kinetic Energy Penetrator (KEP) and the Hydrodynamic Penetrator (HP).[88] The KEP has a maximum impact velocity of 3 kilofeet per second (kfps), about the maximum speed of an SR-71 Blackbird. The KEP destroys the target by shattering it with an enormous blow. Since some areas of a target are more vulnerable to shattering blows than others, precise targeting is necessary for an effective KEP.

The HP has a minimum impact velocity of 8 kfps. When a penetrator strikes a target at this extreme velocity, both target and penetrator react to the collision as if they

were fluids (their behavior described by hydrodynamic equations of motion). The impact attacks the molecular composition of the target, spreading dense impact shocks at enormous speed.

A nagging problem for KEW systems is the heat and shock generated on reentry. This can affect the precise delivery of the weapon. An exciting new concept has been proposed that promises to ameliorate this problem. By concentrating a laser beam in the area immediately in front of the hypervelocity KEW, it is possible to create a laser-supported detonation wave (called an "air spike") that partially shields the KEW. The air spike transforms the normal conical bow shock into a much weaker, parabolic-shaped oblique shock.[89] Researchers estimate that a properly designed air spike could decrease the effects of shock and heat on a hypervelocity object by over 75 percent (making Mach 25 seem like Mach three).

Researchers have also experimented with enhancers for the two basic classes of KEW. Pyrophoric compounds might be added to increase lethality by generating intense heat. Provided extremely high-speed fuses could be developed, explosive charges might be added to increase the weapon's ability to penetrate the target's outer shell. The dense rods or flechettes mentioned above as submunitions for ballistic missiles might also be used by a KEW to increase its area of effect, provided the submunitions could be dispersed properly at these enormous velocities. It has been suggested that low-speed submunitions or dispersed EMP bombs might be used to help the KEW penetrator overcome defensive systems and reach the target.[90]

The high velocities needed by KEW systems can be generated chemically (by rockets) or electromagnetically (by the "rail-gun"). The rail-gun consists of a long, usually evacuated, tube containing electrically conducting rails and surrounded by high-power electromagnets.[91] The projectile is the only moving part. The projectile is placed on the rail and a large current is generated within the rail and the projectile. Simultaneously, time-varying magnetic fields are induced in the magnets with powerful pulsed power supplies. The resulting electromagnetic force rapidly accelerates the projectile to extreme velocities. Rail-guns are being actively studied by the US military, although to date researchers have only been able to accelerate small masses to hypervelocity. Velocities achieved 20 years ago have not been exceeded to this day. Navy technologists report that their main problem lies in developing small, high-power, stress-resistant power supplies.[92]

Finally, an interesting variation on the HP concept involves the use of meteorites as a weapon.[93] Naturally occurring meteorites at least the size of large houses (necessary to survive drag-induced heating in the atmosphere) could be intercepted in space and redirected to a terrestrial target. If done with sufficient stealth and subtlety, the impact could even be "plausibly denied" as a natural occurrence. Meteorites 30 feet in diameter could be counted on to generate nuclear weapon-size explosions (20 kilotons), but without the lingering radiation.[94]

Capabilities

The capabilities of a kinetic-energy projectile would be similar to the better known precision guided missiles (PGM). The kinetic-energy projectile would most likely be a PGM without explosives, but which travels so fast it can take out surfaces as well as targets buried hundreds of feet underground. Moreover, the kinetic-energy projectile can take out single targets or area targets (using hundreds of flechettes or rods). Besides precision, perhaps its most attractive capability is that it is an all-weather weapon. Finally, KEW systems are versatile in that they could be safely launched from the US and find their targets anywhere in the world within 30 minutes, or they could reside in relatively small satellites (storage containers) in LEO, waiting to be dispensed and reach their target within a few minutes. These rather simplistic satellites could

easily be integrated with the global information network (GIN), the "utilities," and a command and control system.

Meteors can be hundreds of magnitudes more deadly than KEWs. However, there are several significant shortfalls to meteorites as weapons. They are hardly a timely weapon—the war fighter must patiently wait for nature to deliver his "ammunition." The uneven shape and heterogeneous composition of meteorites makes it highly unlikely they can be guided precisely to a target. Since it is also impossible to predict how much of the meteorite will survive the fall from space, meteors are best classified as area weapons with a very uncertain radius of effect.

Countermeasures

The countermeasures against KEWs are basically the same as for ballistics missiles, except that the KEWs are envisioned to be considerably smaller. Thus, they would be more difficult, if not impossible, to attack once they begin their descent from space. The countermeasure would best be applied against the KEW delivery platform, be it a small satellite, a TAV, or some sort of pod.

If the KEW uses GPS for terminal guidance, it may be possible to jam the GPS signal. This may be especially effective for protecting mobile targets (the KEW GPS receiver would require real-time updates to hit these mobile targets). However, this would do nothing to prevent the use of KEWs that work strictly on trajectory or an internal guidance and targeting system against static targets.

Evaluation

Meteors, as a weapon, are impractical, even in 2025. Of course, since KEW technology is available today, it will certainly be even more precise and deadly in 2025. A few hundred KEW "storage containers" placed in a LEO would make the timeliness and responsiveness very high (within a few minutes). Precision and reliability would also be high. However, the flexibility and selective lethality would be low—total destruction would be the only choice, unless used as a demonstration of power. Thus, the KEW would not be the ideal weapon of 2025. Due to its all-weather capability, however, it would be a good complement to some other weapon capability.

Space Sortie—Transatmospheric Vehicle

There are numerous single-stage-to-orbit (SSTO) vehicle concepts under active study that should result in development of a transatmospheric vehicle (TAV). These TAV concepts, sometimes referred to as reusable launch vehicles (RLV), are plausible enough that McDonnell Douglas/Boeing, Lockheed/Martin, and Rockwell are all investigating proprietary concepts. Both the Rockwell and Lockheed/Martin RLV concepts are vertical take-off/horizontal landing, have longitudinal payload bays (like the shuttle), and are being designed for commercial payloads. The McDonnell Douglas/Boeing RLV concept is similar except it is a vertical take-off/vertical landing.[95] The US Government (USAF, NASA) is in partnership with McDonnell Douglas/Boeing, Lockheed/Martin, and Rockwell to develop a military/commercial version currently called the X-33. They expect to fly the X-33 RLV in 1999.[96] The McDonnell Douglas/Boeing RLV is a vertical takeoff/landing system with eight rocket engines. It navigates using GPS, will use 200-foot pads instead of runways, and is designed for low maintenance and infrastructure. Development costs are expected to be about the same as a new commercial airliner (Boeing 777).[97]

Whichever concept the US government and industry decide to pursue, a revolution must occur in TAV engine technology before it becomes viable.[98] Conventional rockets have low dry weight (without fuel) and high gross takeoff weight (lots of fuel and oxygen) to reach the Mach 25 speeds that are necessary to reach space. Rockets give up maneuverability and ease of handling in the atmosphere by being so configured. Air

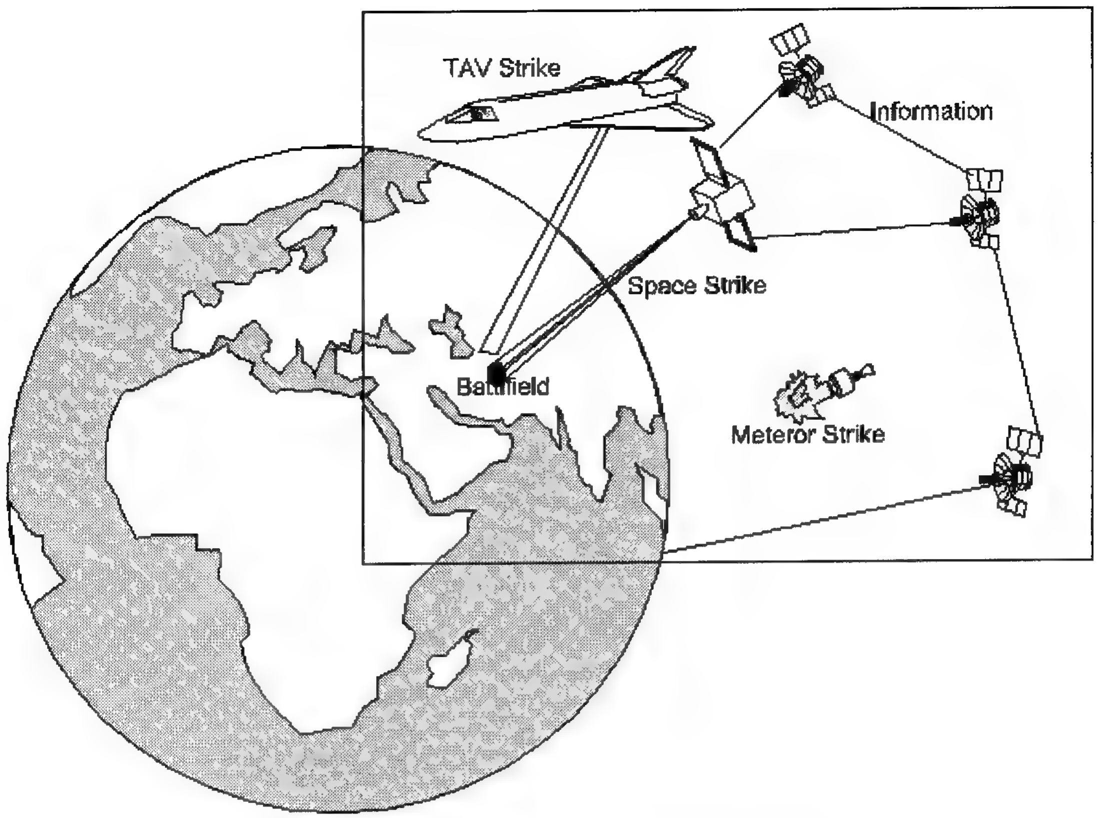


Figure 3-3. The TAV in Its Native Environment

breathers, on the other hand, have high dry weight and low takeoff weight because they use the oxygen in the atmosphere as part of their fuel. They have great maneuverability, but have considerably lower top speeds. Furthermore, the major costs of a TAV are its dry weight components. Fuel, although relatively inexpensive, consumes 80+ percent of the total gross weight, leaving only 3–6 percent for cargo. The 2025 TAV must have moderate dry weight and gross weight, which may be obtained using a combination of rocket and air-breathing technology called a rocket-based combined cycle air-augmentation.[99] This will require a revolution in rocket technology. But three pieces of this revolution will very likely be available by 2025.

The first piece of the revolution deals with the advanced technology "pulse detonation wave" combustion process in a rocket instead of the conventional "constant volume combustion" process. Researchers believe this technology would increase the pressure during detonation by 20 to 40 times and significantly increase the specific impulse (I_{sp}) of the fuel. More importantly, it will decrease (by 20 to 40 times) the pressure, heating, and wear and tear on the fuel turbine-feed pumps that are the cost, reliability, and safety concerns of rocket engines.[100] Thus, rocket engines could be made cheaper, smaller, and more reliable by orders of magnitude. Rocketdyne and Adroit have both been working aggressively in this area.

The second piece of the revolution concerns the "air augmentation" portion of the engine. The leading concept involves wrapping sheet metal with an inlet around the base of the engine. This technique, properly applied, should "squeeze" every bit of oxygen

possible out of the "sensible atmosphere" and make it available as part of the fuel. This would make the air-breathing part of the engine useful at altitudes of up to 120,000 to 140,000 feet and increase the thrust by 300 percent. This alone could double the payload.[101]

The final piece deals with the combuster in the air-breathing portion of the engine. The combuster creates the highest pressure in the engine as the fuel mixes with oxygen, burns, and then provides thrust. As speed increases, between one-third and one-half of the thrust comes not from the fuel, but from the heat and pressure within the engine. Under these conditions, the fuel is not efficient and energy losses increase dramatically, heat increases, and sheer stresses increase, resulting in lower final speeds. However, a revolutionary premix, shock-enhanced (oblique standing detonation wave) combustion engine could increase the I_{sp} by 30 percent. This would allow the combuster to be reduced in length by 75 percent, thus decreasing the weight of the engine significantly.[102]

The final design entails placing the rocket engine inside the air breather. At low Mach speeds, the air breather would be used alone. At Mach 15 to 20 during pull up to space, the rocket would light up and pressurize the air breather, keep burning atmospheric oxygen (would not have to carry nearly as much), and create a synergistic effect using both the rocket and the air breather. The result could be a highly efficient, viable engine for the 2025 TAV.

Lightweight structures are another must for the 2025 TAV. Dr Dennis Bushnell, chief scientist for NASA at Langley, Virginia, reported that the Japanese are working on a Carbon-60 (Fullerine) material that is lightweight, but is an order of magnitude stronger than the most modern composites. He also stated that advances in static stability will help the TAV of 2025.[103] Currently, spent uranium is placed in the nose of vehicles for ballast (keeps center of gravity forward of center of pressure to prevent tumbling); researchers, however, are investigating placing "longitudinal vortices" and using active controls to maintain this positive stability instead of weights. This would allow designers to move things around for efficiency without worrying as much about the center of gravity. Finally, Dr Bushnell reported that the Navy is aggressively researching "designer aerodynamics" and circulation control of air-breathing vehicles. With sensors and actuators, this could give the TAV "bird-like flight" characteristics. Thus, it truly could become an airplane and a space plane.[104]

In addition, the 2025 TAV should be easily upgradable as technology improves. We must not produce a TAV that will become obsolete and difficult to maintain even as we are trying to build it. Modularity of design will be important. For example, as guidance system technology is improved and further miniaturized, maintenance workers can expect to pull out a "black guidance box" and replace it with a new, improved version (lighter, less volume).

Finally, all the systems of the TAV must be integrated with all the other systems that interface with it. Onboard (guidance, maneuvering) and off-board (surveillance, some processing) systems must all work together as a distributed "system-of-systems."

Capabilities

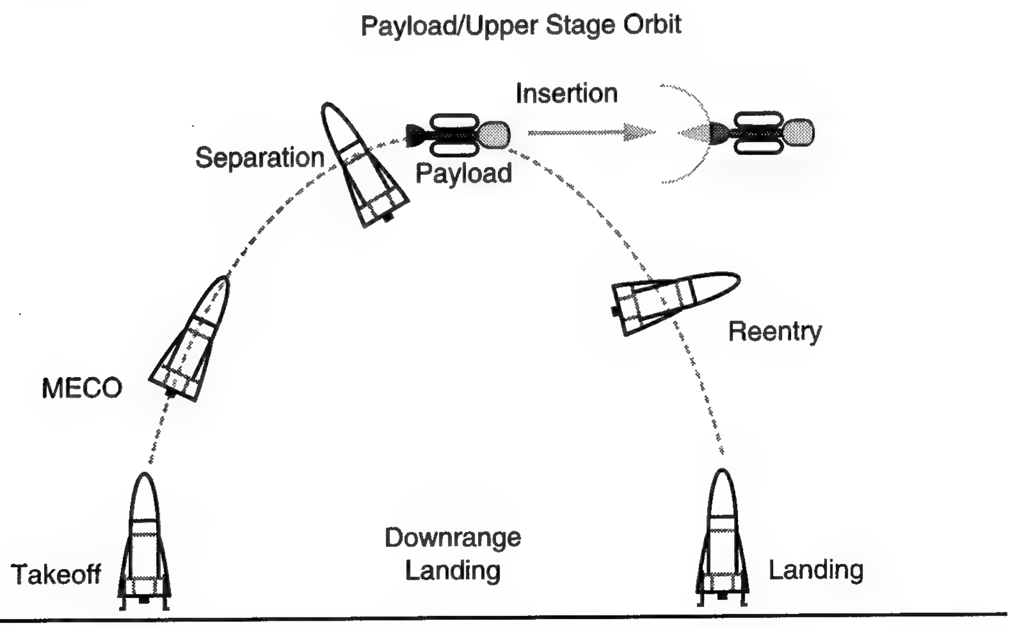
The TAV "fleet" of 2025 will possess incredible capabilities. The TAVs will have highly efficient, reliable engines that perform equally well in the atmosphere or in space; the TAV structures will be made of strong, lightweight composites that are easily replaceable; and the payload capability (weight and volume) will be versatile and adaptable to many different types of payloads and missions. Commercial carriers will exist that are capable of lifting 20,000 to 40,000 pounds into LEO.[105] The Black Horse TAV concept calls for a payload of approximately 5,000 pounds into a LEO

(although some critics believe that due to design flaws, it cannot take any payload into orbit),[106] whereas the X-33 concept proposes a payload of 10,000 pounds (polar orbit) to 20,000 pounds (eastern LEO).[107] The military requirement will probably be in the 10,000 to 20,000 pound range. A versatile TAV should certainly be able to carry payloads for at least three basic missions: (1) to deploy/retrieve small-to-medium satellites (large satellites are "dinosaurs") for many, although not all, missions; the trend is towards small/microsatellites; thus, all of the TAV concepts should suffice for low and medium earth orbit missions; (2) to carry a small team of special operations forces along with their operational gear to crisis spots throughout the world (TAVs would probably need a 2,000-pound capacity to carry four-man teams[108]); and (3) to perform as a sensor and weapon platform (for short periods of time analogous to aircraft sorties).

The satellite deployment/recovery capability could be critical for fielding or reconstituting space-based components of weapon systems in 2025. In fact, using a "Pop-up" flight profile (see fig. 3-4), the TAV could potentially launch multiple satellites and grant access to all orbits (e.g., LEO, Polar, Sun Synchronous, Molniya, geosynchronous earth orbit (GEO). In an eastern LEO, the TAV would be able to deploy 15 1,000-pound small satellites and pick up four to bring back. It could deploy as many as four satellites to a GEO orbit.[109] This capability should make the TAV extremely flexible for space-force applications.

Other necessary capabilities/requirements for a TAV-type vehicle include all-weather performance, rapid call-up time, short turn-around time, long service life, low-maintenance engines, vibration-resistant systems and

"Pop-Up" Flight Profile



Significantly increases payload to LEO

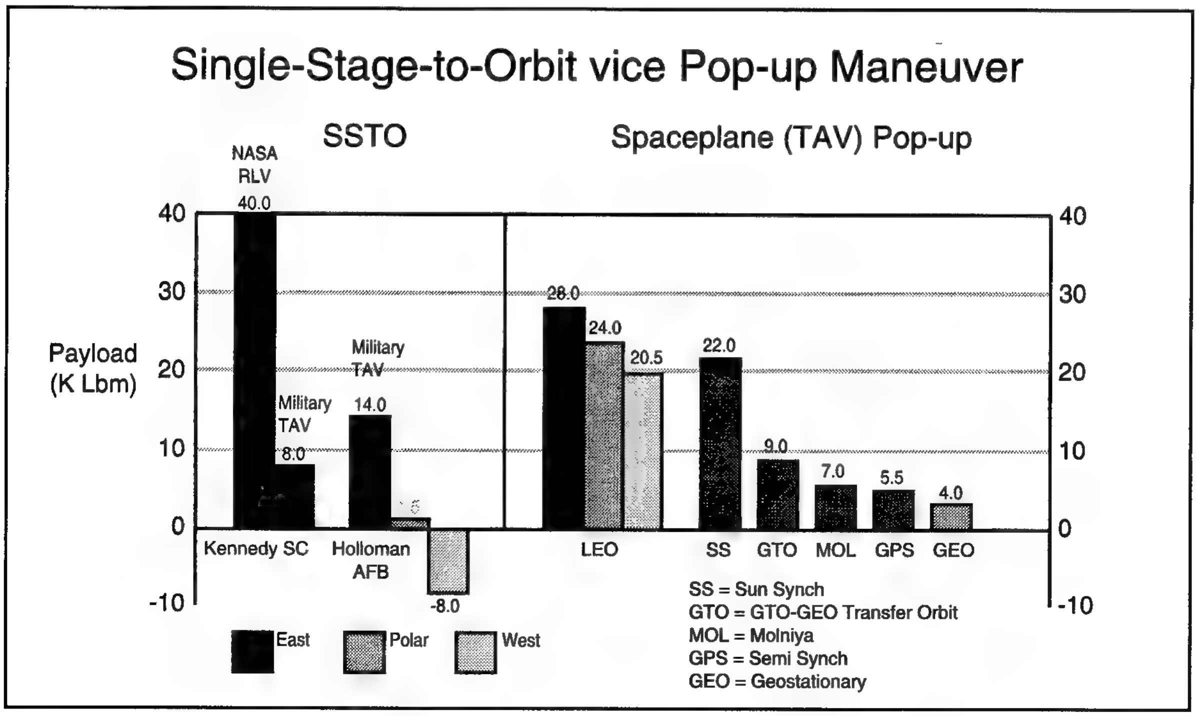
Source: Briefing, Phillips Laboratory PL/VT-X, "Military Spaceplane Technology and Applications," January 1996.

Figure 3-4. Pop-Up Maneuver

structures (to survive reentry and "hyper-cruise" speeds near Mach 25), all azimuth earth access, global range of operation, and the ability to be upgraded easily and inexpensively.[110] The requirements for all azimuth access and global range of operation mean that the TAV will probably need refueling capability. A study by W. J. Schaeffer Associates (4 February 1994) on the feasibility of an aerially refueled "spaceplane" concluded this capability "appears feasible and practical."[111] Refueling could occur in the atmosphere or in space. Call-up times on the order of a few hours and turn-around times of from six hours (emergency) to 24 hours (routine) will probably be required.[112] More importantly, the TAV of 2025, once launched, will reach anywhere in the world within 60 minutes or less. Of the 60 minutes required, approximately 20 minutes would be from launch to space plus another 40 minutes to the target area (a TAV could be over the most likely target areas after only 20 to 30 minutes in space).[113] The 2025 TAV could also deliver multiple payloads (e.g., laser, KEW, reconnaissance, satellites, strike team, ASAT weapon, etc.) depending on the mission.

Countermeasures

Like aircraft, TAVs are naturally vulnerable on the ground and would need protection. Moreover, TAVs emit a variety of easily detected signatures (e.g., radar, enhanced infrared due to high-speed passage through the atmosphere, and acoustic) and are also vulnerable to attack during launch and landing. TAV launch facilities could be safely located in the continental United States (CONUS) but if a team of "space marines" must be landed outside the CONUS, the TAV and its payload would be vulnerable to a variety of weapons



Source: Briefing, Phillips Laboratory PL/VT-X, "Military Spaceplane Technology and Applications," January 1996.

Figure 3-5. Pop-Up Enables Flexible Transpace Operations

(space-based, airborne, or terrestrial) and tactics. Fortunately, a force of three or four TAVs (analogous to a flight of modern combat aircraft in tactical formation) could be extremely difficult to attack if at least one is used as protection for the others. Another consideration is that, during conflict, any US spacecraft (particularly if it is a manned platform) would instantly become a high-value, high-priority target. Thus, ASAT-type weapons could be directed against a TAV in endo- or exo-atmospheric flight. However, the highly maneuverable TAV, if configured to carry high-speed precision weapons on board, could itself become an "anti-ASAT" weapon—the attacking ASAT would then become the target.

Evaluation

Flexibility, because of its ability to put human judgment at the developing crisis location rapidly, is the greatest asset of the TAV. Responsiveness and timeliness, while not in the same class as space-based light-speed weapons, are at least moderate (hours for call up followed by 60 minutes maximum flight time). Since a TAV could carry a broad range of payloads (e.g., many different types of weapons, a special forces unit, or even limited space maintenance and repair facilities), it rates high in precision, survivability, and selective lethality. Reliability as a weapon system for force-application or space-control missions (see ***2025*** counterspace white paper) could be very high, since the TAV could launch active radar or inertially guided weapons (such as KEW devices) through weather conditions that would baffle directed-energy weapons, provided the developmental problems that have plagued spaceplanes can indeed be solved.[114] When not needed as a weapon system, the TAV could "earn its keep" through a variety of useful, nonbelligerent missions such as rapid replenishment/ repair of small satellites, high-value airborne/ spaceborne surveillance and reconnaissance sortie, emergency clandestine low probability of intercept (LPI) communications or command and control link, or (properly configured) even as a truly high-speed airborne warning and control system (AWACS)/ joint surveillance, target attack radar system (JSTARS) platform. A small fleet of TAVs would be a highly flexible, adequately responsive component of an effective space-strike system in 2025.

Table 1
Summary Evaluation of Potential Weapon Systems

	DL	SBL	TAV	HPM	EMP	KEW	BM	NPB	ILL
TIMELINESS	HIGH	HIGH	MED	HIGH	MED	MED	MED	MED	HIGH
RESPONSIVENESS	HIGH	HIGH	MED	HIGH	MED	MED	MED	MED	HIGH
FLEXIBILITY	HIGH	HIGH	HIGH	HIGH	HIGH	LOW	MED	LOW	MED
PRECISION	HIGH	HIGH	HIGH	LOW	MED	HIGH	HIGH	HIGH	MED
SURVIVABILITY	MED	LOW	HIGH	LOW	HIGH	MED	HIGH	LOW	MED
RELIABILITY	MED	MED	MED	MED	MED	HIGH	HIGH	MED	LOW
SELECTIVE LETHALITY	HIGH	HIGH	HIGH	MED	MED	LOW	MED	MED	LOW

Summary— The System-of-Systems

A careful evaluation of the weapon systems discussed in this chapter leads us to eliminate most candidate systems based on the desired capabilities of timeliness, responsiveness, flexibility, precision, survivability, reliability, and selective lethality. A summary of the evaluation can be found in table 1, where the following potential weapon systems are listed: the distributed laser (DL) (e.g., earth-based laser or space-based mirror); the space-based laser (SBL); the TAV itself; the space-based HPM; the EMP weapon (as a small, conventionally triggered bomb only); the hypervelocity KEW (as a payload on a TAV); other projectile weapons (ballistic missile payloads or BM); space-based NPB; and the "illusion weapon" concept (ILL). Each potential system's "score" against a desired capability is given as high, medium, or low.

Large space-based weapon platforms are eliminated because they are not considered to be survivable in 2025 or practical in terms of weight, cost, size and in most cases power requirements (incoherent light, NPB, HPM weapons). EMP weapons are eliminated because they lack flexibility, are not precise enough to limit collateral damage, and their selective lethality is at best questionable. Projectile weapons, while very precise, are eliminated because they are not considered to be highly flexible or capable of providing selective lethality. ILLs are ruled out because they do not provide the redundant signatures (e.g., optical, infrared, radar, and so on) that would make them sufficiently believable and because these notional weapons, too, do not provide selective lethality.

As we carefully studied the characteristics and capabilities of the various candidate weapon systems, it became evident that there was no one "super weapon system" that could do all the things the US government would require in 2025. This is not a surprising conclusion—earth-based weapon systems have always complemented each other. We call the weapon *system-of-systems* that best addresses the US government's likely requirements in 2025 and incorporates an optimum mix of desirable capabilities the Global Area Strike System (GLASS). GLASS consists of (1) a directed-energy weapon (DEW) system based on the continuous wave laser described previously, and (2) a TAV system (manned or unmanned), which will be used primarily as a weapons platform. The DEW system is composed of powerful earth-based lasers that "bounce" their high-energy laser beams off space-based mirrors to reach the target. The desired TAV is a flexible platform capable of employing compact, onboard DEWs and KEWs when the space-based mirrors are out of range, disabled, or otherwise unavailable for use. The TAV can also deliver KEWs to mobile or stationary targets; drop special operations strike teams to any hot spot in the world; carry EMP bombs, jamming devices, or a myriad of more conventional weapons; and carry small satellites into space or retrieve them from orbit. Perhaps most significantly, the TAV can also be used to sustain and maintain the GLASS constellation of space-based mirrors.

What would the GLASS system-of-systems look like? The DEW system would consist of a distributed complex of earth-based lasers (located in the CONUS) that direct their beams (continuously variable in output power) to a constellation of adaptive, space-based mirrors (10 to 20 meter diameter depending on the laser wavelength and spot size desired at the target). The mirrors would have moveable covers to protect their surfaces when they are not in use, solar cells and/or chemical fuels for prime power (with small, efficient batteries for backup), an advanced pointing and tracking system, an on-orbit attitude control and maneuvering system and adaptive beam-sensing and control system (a more capable version of today's Guide Star technology), and a communications package for C^3 and for linking with the global information network described in appendix B.

The mirrors would be placed in one or more low earth orbits (250 to 500 nm) to reduce the target range, thereby minimizing the amount of laser power required to accomplish the mission and decreasing the pointing and tracking requirements. The use of a number of different orbits and inclinations might be necessary to increase the survivability and operational availability of GLASS. According to reputable studies, at least 24 to 32 orbiting platforms would be needed to ensure reasonable global access.[115] However, the requirement for near-instantaneous response could drive the size of the space-based constellation to more than 100 mirrors. Obviously, the actual size of the constellation of mirrors must be determined by a detailed technical analysis beyond the scope of this white paper.

Capabilities

The capabilities previously discussed separately for the laser, the KEW, and the TAV apply to the GLASS. It will be able to perform strategic, operational, and possibly tactical missions. All of these will involve targeting and applying force to both static and mobile targets. The effects on and types of targets for the lasers, the KEWs, and other possible weapons (using the TAV as a platform) were discussed at length earlier in this chapter.

It is important to note that the laser and/or TAV (with KEWs/other weapons) give the GLASS a full range of lethality—from temporary denial and disruption to partial damage to complete destruction (as described in the sections on the laser and KEW weapons). The laser provides near-instantaneous response time, a light-speed attack that negates all conceivable forms of active defense, and the ability to strike anywhere on the planet. The requirement for a global, all-weather strike capability might be met by using a different laser wavelength to "burn" a hole through clouds, smoke, or aerosols (using the same mirror or a different one) or by employing alternative weather-control techniques before striking for effect. With a well-designed, distributed laser network based in the CONUS, there should always be several ground-based lasers with clear enough skies to fire. However, when times arise when it is impossible to use the laser (e.g., when the target itself is "weathered in"), the TAV will be able to respond to crises on short notice (two to six hours depending on container package required), putting human judgment and human adaptability "on site" as needed.

In the world of 2025, the GLASS can become America's "forward presence without forward basing." This system-of-systems can be used to extend America's eyes and fists around the globe in near real-time while minimizing the need for vulnerable overseas infrastructure and forward deployment of personnel. The GLASS can be global power and global awareness all in one package without actually placing any weapons in orbit (TAVs carry weapons *through* space in a manner entirely analogous to the modern ICBM).

The GLASS is a powerful concept, but it cannot function independently. Both the DEW and TAV-mounted KEW will require real-time external handoff of precise target location (and possibly target characteristics); a credible "identification friend or foe" (IFF) capability; and a secure command and control system. The DEW will also require real-time information on battlefield, atmospheric, and space weather conditions that could affect beam propagation and target coupling. Beam-control systems with submicroradian pointing and tracking accuracies with active satellite vibration and thermal control systems for space-based platforms will also be needed. Powerful SAT/BDA with onboard processing systems will be essential to acquire and track mobile targets. The TAV will also require real-time information on battlefield conditions (especially to avoid fratricide and "friendly" kills). When the TAV-mounted KEW is used, it will require hypervelocity flight control, high-g and high-temperature flight

hardening, and smart fusing. A method for maintaining tracking and control during the terminal phase despite the sheath of hot, shocked gas surrounding the reentry projectile may also be required.

To fully exploit the global omnipresence of sensors and the proliferation of sensor types in 2025, the SAT/BDA system should be given near-real-time access to the global surveillance and reconnaissance and communication systems. The ability to receive and interpret other views of the target will greatly enhance the mission success rate, and might prove to be the enabling capability for some weapon concepts.

Countermeasures

The countermeasures previously discussed in this chapter for the coherent light laser and the TAV still apply when they are employed separately to engage targets. However, when employed as a system, the enemy would have to target the ground-based lasers (virtually all of them) and the TAV launch sites (again, nearly all of them) to disable GLASS—a daunting task when you realize that most of GLASS's components are based in the CONUS. If the enemy only attacked a few space-based mirrors or a few TAVs, the remaining CONUS-based TAV fleet could quickly (within a day) reconstitute a significant portion of GLASS's constellation of orbiting mirrors. Moreover, the enemy must remember that these two components of the GLASS—the laser and the TAV—are also very robust. That is, not only can they apply force upon the enemy, they can protect each other. The laser can hit targets, in space or on earth, that threaten the TAV launch sites, the ground-based lasers, or the mirrors, and the TAV can likewise respond to these same threats, but with more flexibility (launched quickly into any orbit with a wide variety of weapons).

Weather and atmospheric conditions will always be a concern for the GLASS. As stated before, the laser can be blocked or at least degraded by cloud cover. The weather modification concepts discussed in the associated ***2025*** white paper may therefore be needed to provide all-weather, space-strike capability.[116]

The cost of the GLASS is a large concern. Space systems are inherently expensive due to the high cost of space lift and the difficulty of designing and building systems to operate for long periods of time in the hostile space environment. Moreover, projecting what a system will cost 30 years in the future is quite risky, especially using technologies yet to be developed. Planners have not had great success in projecting system costs accurately even two to five years in the future.

McDonnell/Boeing claims that the cost of developing a TAV system would be the same as the development cost of the Boeing 777—about $5 billion. This estimate may be close, considering that a Boeing 777 has about 80,000 parts, whereas a TAV, although operating in space, would have only about 30,000 parts.[117] The cost to produce a single TAV would probably be similar to the cost to produce a B-2 bomber—$750 million to $1 billion. However, if the government does not drastically improve its cumbersome acquisition process, these costs could rise dramatically in the coming decades. Fortunately, with the many space mirrors and the fleet of TAVs required by GLASS, and the hundreds (if not thousands) of satellites proposed both in other ***2025*** white papers and in advertised commercial space systems (Iridium, Teledesic), government and industry should be able to develop stable production lines that produce relatively inexpensive, identical satellites instead of the large, hand-built, unique satellites of today. The US must certainly keep an assembly line (both commercial and military) going for production of the TAV. America's TAV must not become merely an advanced version of the Space Shuttle—available in small numbers at astronomical cost and with limited usability.

The cost of a directed-energy weapon system that includes ground-based continuous wave laser stations and a constellation of

space-based mirrors is more difficult to project since there is no present space-based weapon system to use as a baseline. The USAF is currently developing an airborne laser system (ABL) as a boost-phase ballistic missile defense system. The USAF expects to spend approximately $5 billion to design, test, and field a small number of operational airborne laser systems.[118] Development costs alone for a distributed system with a space-based element (the mirrors) would be at least as great as this.

The likely cost of some individual components of the DEW element of the GLASS can also be forecast. A high-quality, properly figured and polished laser mirror about 15 to 20 meters in diameter will cost between $20 and $30 million for the substrate alone (coatings will cost more). The total cost of the support structure and mirror will be in the range of $60 to $90 million. Provided the technological challenge of power scaling for solid-state and/or diode lasers can be met, the cost of a single ground station including a megawatt-class laser and its associated infrastructure will be on the order of approximately $100 to $200 million (USAF experts forecast the cost of a 100-megawatt chemical laser alone at $50 to $100 million).[119]

Notes

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2. ***2025*** Concept, no. 900610, "Hoversatt," ***2025*** Concepts database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

3. ***2025*** Concept, no. 900338, "Stealth Technology," ***2025*** Concepts database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

4. Lt Col Henry Baird et al., "Spacelift -Integration of Aerospace Core Competencies," ***2025*** Study (Maxwell AFB, Ala.: Air War College, 1996).

5. US GAO Report, "Ballistic Missile Defense - Information on Directed Energy Programs for FY 1985 Through 1993" (Washington, D.C.: Government publication, GAO/NSIAD-93-182, June 1993), 13.

6. Personal interview with Dr M. Yarymovitch, 7 February 1996.

7. *SPACECAST 2020*, "Refueled Transatmospheric Vehicle" (Maxwell AFB, Ala.: Air University Press, 1994), H-1.

8. ***2025*** Concept, no. 900046, "Space Marine Operational Theater"; ***2025*** Concept, no. 900202, "Space-based Special Operations Forces"; ***2025*** Concept, no. 900696, "Global, Rapid Response Space Sortie"; ***2025*** Concept, no. 900265, "Space Storage Modules To Establish Space-sourced Air Drop Capability"; ***2025*** Concept, no. 900654, "Parts Locker," ***2025*** Concepts database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

9. Briefing, subject: "Military Spaceplane Technology and Applications," January 1996, Phillips Laboratory PL/VT-X, slide 17.

10. Lt Col Edward F. Murphy et al., "Information Operations: Wisdom Warfare for 2025," ***2025*** Study (Maxwell AFB, Ala.: Air War College, 1996); and Lt Col William Osborne et al., "Information Operations: A New Warfighting Capability," ***2025*** Study (Maxwell AFB, Ala.: Air War College, 1996).

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12. ***2025*** Concept, no. 900163, "Solar Energy Weapon"; ***2025*** Concepts database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

13. *SPACECAST 2020*, "Force Application" (Maxwell AFB, Ala.: Air University Press, 1994), O-18.

14. Personal observations made by one of this paper's authors at the Litton-Itek Corporation and the University of Arizona in March 1992 and February 1993.

15. Personal interview with Dr M. Yarymovitch, 7 February 1996.

16. Information obtained from senior DOD professionals speaking to the Air War College under the promise of nonattribution.

17. Lt Col Brad Shields et al., "Weather as a Force Multiplier - Owning the Weather in 2025," ***2025*** Study (Maxwell AFB, Ala.: Air War College, 1996).

18. *SPACECAST 2020*, "Force Application," O-18.

19. ***2025*** Concept, no. 900181, "Blackhorse Type Outer Atmosphere Low Orbit Vehicle" (Proprietary); ***2025*** Concept, no. 200018, "Space-Based Laser Designator," (Proprietary); ***2025*** Concept, no. 900420, "Laser Attack Station"; ***2025*** Concept, no. 900452, "Space-based Satellite Body Guard"; ***2025*** Concept, no. 200034, "Missile Laser"; ***2025*** Concepts database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

20. Information from Air Force Institute of Technology (AFIT) graduate course in Laser Effects, Dr William Bradley, 1984.

21. "Visions" briefing, slide 21.

22. Briefing, subject: "Ongoing Research in the Directorate," Phillips Laboratory's Lasers and Imaging Directorate, provided to the ***2025*** study team in November 1995.

23. Ibid.

24. Information obtained through personal interviews by one of this paper's authors with industrial experts in 1981, 1993, and 1994 under the promise of nonattribution.

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26. *SPACECAST 2020*, "Force Application," O-18.

27. The aperture sizes were determined by simple optical diffraction calculations at low earth orbit ranges (hundreds of kilometers vertically; a few thousand kilometers slant range) for wavelengths from 5 microns to 0.45 microns assuming a Gaussian beam with 99%+ energy on target and a circular aperture. For more information on how to perform these calculations, see (for example) Anthony E. Seigman, *Lasers* (Mill Valley, Calif.: University Science Books, 1986), chap 18.4 ("Aperture Diffraction: Circular Apertures"), 727. For aberrated beams, even larger mirrors would be required.

28. These numbers obtained by a simple geometric calculation. At an orbital altitude of 300 to 1,000 km, angular accuracies in this range are required to achieve pointing stability on the order of inches.

29. US GAO Report, "Ballistic Missile Defense - Information on Directed Energy Programs for FY 1985 Through 1993," 38.

30. Briefing, subject: "Ongoing Research in the Directorate," provided to the ***2025*** study team in November 1995.

31. John L. Petersen, *The Road to 2015* (Corte Madera, Calif.: Waite Group Press, 1994), 58–60, 297–98. Intriguing ideas based on nanotechnology and microelectromechanical machines (MEMS) were also submitted as ***2025*** Concept, no. 900518, "Electronic Grid - Throwaway Sensors"; ***2025*** Concept, no. 200023, "Surveillance Swarm"; ***2025*** Concept, no. 900231, "Gnat Robot Threat Detectors"; ***2025*** Concept, no. 900288, "Swarms of Micromachines"; ***2025*** Concepts database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

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35. Lt Col Brad Shields et al., "Weather as a Force Multiplier - Owning the Weather in 2025," ***2025*** Study (Maxwell AFB, Ala.: Air War College, 1996).

36. ***2025*** Concept, no. 900426, "Atmospheric Disturbance"; ***2025*** Concept, no. 900552, "On-demand Tactical Recce Satellite Constellation"; ***2025*** Concept, no. 200018, "Space-based Laser Designator," ***2025*** Concepts database (Maxwell AFB, Ala.: Air War College/***2025***, 1996). See also the briefing by Phillips Laboratory's Lasers and Imaging Directorate provided to ***2025*** study team in 1995.

37. US GAO Report, "Ballistic Missile Defense - Information on Directed Energy Programs for FY 1985 Through 1993," 19.

38. The core of this idea can be found in the briefing charts from the 10 April 1995 working session of the New World Vistas team in the section on the Directed Energy group (chairman Donald Lamberson, Maj Gen, USAF (Ret.)). See also briefing by Phillips Laboratory's Lasers and Imaging Directorate provided to ***2025*** study team in November 1995.

39. Amnon Yariv, *Introduction to Optical Electronics*, 2d ed. (New York: Holt, Rinehart, and Winston, 1976), 166–67, 176–86.

40. Anonymous assessor comment on first draft of Space Operations white paper, ***2025*** Concepts database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

41. Briefing by Phillips Laboratory's Lasers and Imaging Directorate, November 1995.

42. Personal visit by one of the authors to the Lawrence Livermore National Laboratory's inertial confinement fusion facilities in 1984.

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49. *SPACECAST 2020* "Force Application," O-22, O-23.

50. US GAO Report, "Ballistic Missile Defense - Information on Directed Energy Programs for FY 1985 Through 1993," 30.

51. Ibid., 30.

52. "Visions" briefing, slide 18.

53. US GAO Report, "Ballistic Missile Defense - Information on Directed Energy Programs for FY 1985 Through 1993," 31.

54. Personal interview with Dr M. Yarymovitch, 7 February 1996.

55. US GAO Report, "Ballistic Missile Defense - Information on Directed Energy Programs for FY 1985 Through 1993," 31.

56. Carlo Kopp, "A Doctrine for the Use of Electromagnetic Pulse Bombs" (Fairbairn ACT, Australia: Air Power Studies Centre, July 1993), 1, 11.

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68. ***2025*** Concept, no. 200009, "Pyrotechnic Electromagnetic Pulse (PEP)"; ***2025*** Concept, no. 900270, "EMP Pills," ***2025*** Concepts database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

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72. Kopp, "A Doctrine for the Use of Electromagnetic Pulse Bombs," 9.

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108. Briefing, A discussion paper-as-briefing, 26 January 1996, "Space and the Army's Future," slide 5.

109. Briefing, subject: "Military Spaceplane Technology and Applications," January 1996, Phillips Laboratory PL/VT-X, slide 19.

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117. Information obtained from the internet, Internet 14 February 1996, available from: http://www.contribu.cmu.edu/usr/fjo4/ and conversations with representatives at a briefing on the military spaceplane, 6 March 1996.

118. Ralph Vartabedian, "Lasers Next Great Hope to Beam Defense Systems into Future," *Los Angeles Herald*, 3 December 1995.

119. Maj Michael Roggemann, Air Force Institute of Technology (AFIT) professor, telephone interview with author, 28 March 1996.

Chapter 4

Concept of Operations

The threat-dependent concept of operations for the GLASS is relatively straightforward. Threats could be slowly developing situations, fast-developing crises, or surprise attacks from a country or a terrorist-type group (where some quick retaliatory response is required). In addition, the intensity of the threat could vary over a broad range from mere intimidation to an isolated terrorist attack, a small war or battle, or (inevitably) total war. No matter what type of threat or situation develops or what its intensity, the global coverage provided by GLASS will allow decision makers to direct action that is responsive and timely (i.e., near instantaneous), flexible in terms of the full spectrum of lethality (i.e., from "lighting up" the battlefield to destroying platforms and assets), precise (i.e., pinpoint accuracy if necessary), survivable (i.e., dispersion of vulnerable space-based assets, self-protection capability, and CONUS-basing of the highest-value components), and reliable (i.e., TAV will be able to serve as backup). In summary, GLASS provides global coverage and a broad range of nearly instantaneous responses without extensive forward basing.

In the first instance of a slowly developing situation involving the US and its allies, the GLASS would be used primarily as a deterrence weapon. However, it is much more flexible than today's nuclear-deterrent weapon. The nuclear bomb may well have prevented a catastrophic total world war, but it has not stopped any of the hundreds of relatively minor conflicts (at all levels) that have continued to rage since 1945. The GLASS, able to project force across a wide spectrum of outcomes, could actually be employed in scenarios ranging from humanitarian operations (e.g., in its surveillance or illumination modes) to major regional conflicts (i.e., to disrupt, damage, or destroy the enemy's strategic assets). These operations do not necessarily have to be lethal. That is, the US could select a benign target, notify the rogue government of the time and place at which the offending item will be neutralized, and then disable or destroy the target (and *only* the target) with a laser beam and/or hypervelocity projectile. After a few demonstrations of this capability, even the most isolated totalitarian rogue state would realize none of its offensive assets are safe and (just as important) there will be no collateral damage to show the news cameras. Clearly, in addition to the straightforward destruction of military targets, the GLASS could be used for deterrence, intimidation, persuasion, or just to forcefully signal America's resolve.

GLASS could also be put to effective use in the most fast-developing crisis. For example, suppose a country in northern Africa masses tanks on its border to invade a nearby country and its leadership will not listen to American or UN requests to reverse this provocative action. A cluster of small projectiles could be dropped from a TAV to destroy a critical tank concentration while laser beams "from heaven" are burning holes through advancing combat aircraft and blowing up fuel storage areas and munitions dumps. Even a modern war machine could be stopped dead in its tracks before it even gets started, since the GLASS can strike strategic, operational, and tactical targets, simultaneously performing strategic attack, interdiction, and even close support missions.

In the third situation, where an attack has already occurred and a response is required, the GLASS could be used in a myriad of ways to retaliate and with a speed limited only by the time required for US leadership to make its decisions. For example, the mission may be to eliminate the leadership of a terrorist organization

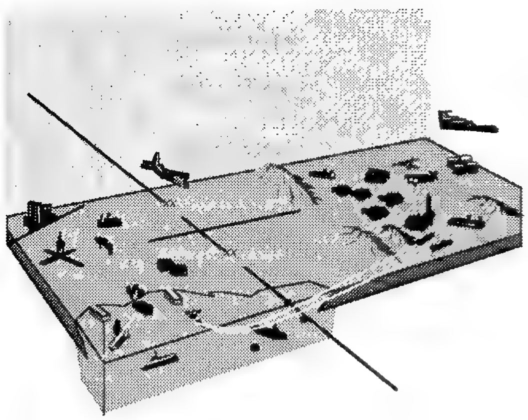

Figure 4-1. TAV Employing Kinetic-Energy Weapons

located at a "safe house" in the largest city of a rogue state. A precision projectile could be dropped from an orbiting TAV that was launched only an hour before and within minutes, the house along with the leadership would be destroyed. It would not matter if the safe house was reinforced with concrete or buried underground; with good intelligence, literally no target on earth would be safe from the GLASS. More importantly, there would be no political fallout from collateral damage. Current weapon systems must generally make do with targeting data accurate to one- to 10-meters at best.[1] This is not the optimum situation for precision-guided or precision-aimed weapons. Such enormous destructive power must be controlled precisely to avoid unnecessary collateral damage. Acceptable targeting data in 2025 will be measured in centimeters, not in meters.

If an area is not covered by the weapon constellation (this will occur at times), the TAV would be sent up with a mobile mirror for the ground-based laser and/or a container of hypervelocity projectiles to cover the target area. Although not as responsive as space-based assets, a TAV could reach anywhere on earth within 60 minutes after its crew climbs on board.[2] The TAV could also carry other types of weapons such as some of those discussed in chapter 3. For deterrence, the US could launch numerous TAVs in unpredictable orbits that remain in space until the crisis is resolved. Three TAVs could provide coverage of most of the earth's current trouble spots every 90 minutes.[3] Of course, the TAV would also be ideal for space control and space superiority. These issues are further explored in other white papers.[4]

The GLASS would also be ideal for counterproliferation operations. The engagement would involve a system-to-system interaction with fixed or mobile ground targets with support from communication, navigation, and surveillance systems. Using the GLASS, the US would not need permission from neighboring nations for landing or overflight rights and could strike a rogue state with a "launch or lose" mentality without *any* prior warning. These desirable functions could be performed without forward deployment of forces, drastically reducing the danger to US military personnel. The flexibility and response time of the GLASS in its role as a counterproliferation asset would be unmatched.[5]

The laser portion of the GLASS has three important characteristics: the weapon itself (photons) travels at light speed, it can be precisely controlled and aimed (not *inherently* a weapon of mass destruction), and it is not

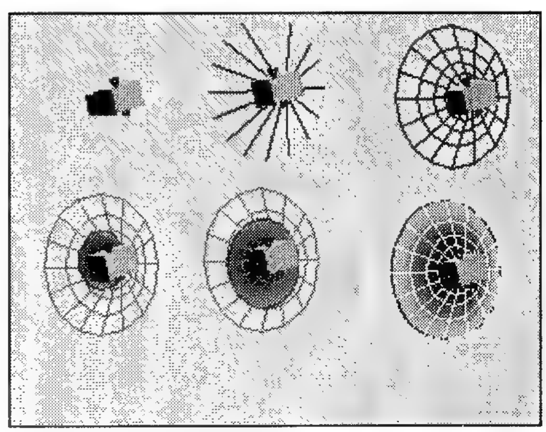

Figure 4-2. Notional Space-Based Mirror Deployment Using Inflatable Mirror Technology

necessarily a line-of-sight weapon (i.e., it can be relayed by mirrors). Possession of a light-speed weapon would revolutionize the conduct of future wars. John Moyle of the Strategic Assessment Center describes this capability as the way to "get inside" the opponent's OODA loop, since, "The means with which one can destroy an enemy's system . . . operates at the same speed as the flow of information, the critical component of the enemy's ability to counter/ defend against the strike in the first place."[6] It may be impossible to mount an active defense against a light-speed weapon.

Geometry is another aspect of the concept of operations. The question, "from where to where?" captures the essence of military space operations and frames the geometry of different force-application missions. Regardless of the purpose of an operation, its beginning and ending locations have tremendous impact on the nature of the operation and its success. The basic geometries for military space systems include earth-space-earth and space-earth. The GLASS employs the earth-space-earth geometry through both the TAV and the DEW system (which is both distributed and dispersed in two mediums—earth and space). That is, the GLASS begins its mission within the earth's atmospheric envelope, traverses the space environment, and then applies force to resolve or influence a conflict occurring primarily within the earth's atmospheric envelope (we do not foresee wars *in* space by 2025). This application of force may involve physical destruction or more subtle effects such as battlefield illumination, support for deceptive information-warfare attacks, or C^2W/EW against an adversary's electronic communications and/or electronic order of battle. The latter distinction is crucial since, in 2025, an adversary's center of gravity may not be a physical object at all, but rather an intangible communications link, information flow, or public attitude.

Basing is also a prime consideration. The laser beams of the DEW system will originate from powerful facilities dispersed around remote parts of the CONUS. Sunny, clear areas such as the American southwest would be the most likely choices. With a laser system that uses space-based mirrors, there are several advantages to using an earth-based laser located in the US (or its possessions): no forward basing is required, there are no concerns about foreign governments demanding removal of US assets from their territories, no weapons are actually placed in space, and the most expensive and maintenance-intensive portions of the system are all ideally placed for access by the US sustainment system. Yet the US would still have tremendous capabilities for power projection. Dispersion of the laser stations is also desirable to enhance the security, reliability, and flexibility of the system and to provide concentration of mass in strategic attacks by allowing GLASS to focus several laser beams on a single hardened target simultaneously.

The TAV element of the GLASS is projected to operate out of at least six CONUS locations and seven locations outside the CONUS, including Alaska, Guam, and Hawaii. This also allows for security and flexibility. If TAV takeoff/ landing is vertical, pads of 200 square feet with airplane-like facilities are required. If the TAV is a horizontal takeoff/landing system, then runways of 8,000 feet will probably be required—less than that needed for most modern jets today. Thus, the TAV fleet could be based at many possible locations (with a large number of already existing backup landing sites).[7]

The infrastructure for the TAV would be similar to that of aircraft today. That is, the ground site would need a fueling capability, a loading capability (change containers in and out), maintenance facilities, and 200-foot-square launchpads (if it evolves into a horizontal landing vehicle, it would also require an 8,000-foot runway). With miniaturization of electronics (thus, portable maintenance equipment), "black box" concepts, "containerized" payloads,

and so forth, the number of supporting ground personnel and equipment should be greatly reduced in comparison with that required for today's military aircraft. In short, the logistics tail would be greatly reduced. Thus, the TAV would have "home bases," but it would be capable of rapidly deploying into many locations during times of tensions and increased hostilities.

The ground-based laser would necessarily require a large power source, a cooling system (possibly employing a high flow of chilled water), and relatively clear skies. This would require relatively isolated basing away from population centers. The power sources would be similar to those that exist today, but they would be more compact, self-contained, and more easily maintained. Of course, the power sources and lasers would be fixed, so significant ground-based security forces, and possibly point defenses against ballistic missiles, would be required. The more ground sites available, the less vulnerable the system is to attacks, the more targets could be hit simultaneously, and the greater the likelihood that the system would be available to attack a given target at need. In addition, tracking, monitoring, and control sites would be required for the mirrors. However, these would not necessarily have to be dedicated sites. That is, they could be integrated into the same system the US uses to track, monitor, and control other space assets. The idea would be to automate as much as possible, build in reliability and maintainability, and standardize procedures and equipment from the beginning of development.

The total number of TAVs the US should procure depends upon the other missions, besides GLASS, that are required. For our purposes, however, the US should procure 12 to 16 operational TAVs. These would be divided into three combat space squadrons, each having the following missions: precision attack, reconnaissance/ surveillance, space lift, satellite support, and "other missions as required."[8] These squadrons would fall under a central controlling authority that would also control the laser stations or bases. Thus, the synergistic effects of the laser and the TAV would be realized (see fig. 4-3).

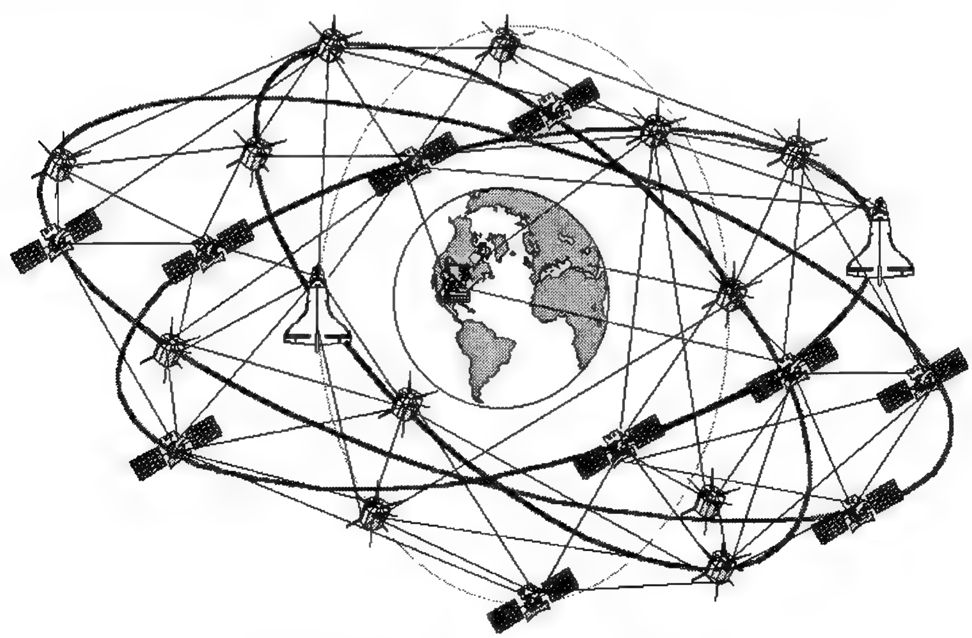

Figure 4-3. The Crowded "Skies" of 2025

Figure 4-4. A TAV in Space-Strike Mode

A TAV (fig. 4-4) could be used to perform a myriad of space operations. The possibilities include deployment, repair, or retrieval of satellites (other than just the GLASS); deployment of smart munitions other than the kinetic energy weapon (usually from LEO); and functioning temporarily as a space-borne command post.[9] TAVs could respond quickly to contingencies with tailored mission packages. Missions ranging from emergency satellite repair/deployment, to dropping a special operations team in the middle of a hostile environment, to mending a gap in a critical satellite constellation would all be possible. In addition, a small fleet of TAVs could allow for the placement of mass (in limited quantities) at critical nodes in a conflict situation. Perhaps the most important advantage might be the psychological effect of possessing such a capability. America's enemies would always have to factor in an almost immediate American response into their hostile actions.

The human-in-the-loop concept is, by itself, neither an advantage nor a disadvantage. That is, humans will certainly be "in the loop" at the critical point in any application of force. This critical point could involve action on the ground or in space. If force is being applied by a light-speed, directed-energy weapon, the delay between the decision to take action and "fire on the target" might only be measured in seconds, but human decision and human judgment would still be intimately involved.

There are decided disadvantages to putting humans in space. To begin with, a human in space would immediately become a prime target during a conflict, especially if the human is the critical link in the weapon system. Moreover, space is a hostile environment—especially near the Van Allen radiation belts; thus, the necessary safety factor increases the overall cost and complexity of the weapon system. In addition, the space operations missions involving the TAV are limited, since current TAV concepts are designed only for LEO operations (limits access to space assets). Timeliness or responsiveness is also relatively limited for manned space systems. An on-orbit, unmanned space-based weapon could take action in a fraction of a second; a manned TAV might require up to an hour to arrive at the crisis location. The TAV is also extremely vulnerable during takeoff, orbit insertion, and landing. A nation could attempt to keep man in space at all times, but the costs involved are believed greater than those of the TAV, on-orbit logistics is extremely expensive, and a permanent manned presence in orbit invites "hostage taking" via ASAT. Thus, there will always be risks for this integral part of the GLASS weapon system.

Notes

1. Maj James G. Lee, USAF, *Counterspace Operations for Information Dominance* (Maxwell AFB, Ala.: Air University Press, October 1994), 14. See also Capt Kimberly M. Walker, USAF, and Capt Tery L. Donelson, "Space Operations Training Course - Chapter 10: Navstar Global Positioning System" (Peterson AFB, Colo.: 1994), 152.

2. *1992 Global Reach-Global Power* white paper.

3. Briefing, subject: "Military Spaceplane Technology and Applications," January 1996, Phillips Laboratory PL/VT-X, slide 27.

4. Lt Col Robert H. Zielinski et al., "Star Tek - Exploiting the Final Frontier: Counterspace Operations in 2025," ***2025*** Study (Maxwell AFB, Ala.: Air War College, 1996).

5. Briefing, subject: "Military Spaceplane Technology," slide 12.

6. John Moyle, memorandum entitled "Thoughts on the Revolution in Military Affairs," 1.

7. Briefing, subject: "Military Spaceplane Technology," slides 12 and 21.

8. Ibid., slide 2.

9. ***2025*** Concept no. 900265, "Space Storage Modules to Establish Space-Sourced Air Drop Capability"; ***2025*** Concept, no. 900654, "Parts Locker"; and ***2025*** concept, no. 900249, "Geosynchronous Manned Command and Control Module," ***2025*** concepts database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

Chapter 5

Investigation Recommendations

We know from even the most casual study of military history how fallible man is in matters concerning war and how difficult it has been for him, mostly because of the discontinuity of wars, to adjust to new weapons. Yet compared to the changes we consider now, those of the past, when measured from one war to the next, were almost trivial. And almost always in the past there was time even after hostilities began for the significance of technological changes to be learned and appreciated.

—Bernard Brodie

The concepts discussed in this paper directly address the needs of the military's most forward-thinking senior planners. Volume four (Future Capabilities) of Joint Planning Document FY 98-03 states that, to achieve joint war fighting objectives, we must develop the "capability to destroy selected targets with precision while limiting collateral damage. Includes precision guided munitions, surveillance and targeting capabilities. Requires advances in sensors, guidance and control, and lethality."[1] Joint Vision 2010 calls for

> long range precision capability, combined with a wide range of delivery systems . . . the ability to generate a broader range of potential weapons effects, from nonlethal to hard target kill . . . these improvements will result in increasingly discrete and precise capabilities, selected to achieve optimum results and applicable to both combat and other operations.[2]

The *New World Vistas* team predicts "space-control and projection of force from space technologies will become as important [as global observation and global situational awareness] in the twenty-first century as global technology for utilization of space becomes more available to many countries of the world."[3] Achieving these desirable capabilities will not be easy and it will not happen overnight. We must begin work now if we wish to be ready for the world of 2025.

Directed-Energy Weapons

Directed-energy weapons operating at or near the speed of light offer the greatest opportunity for sudden, precise attacks across the spectrum of force against a wide range of targets. Reliable, effective directed-energy weapons will not be possible without compact, high-capacity power supplies. Today's solar power technology is insufficient—too much time would be required between shots to regenerate the system's energy reserves. Large, lightweight space structures of particular kinds are also critical. Laser space-strike systems require large, lightweight, optically smooth adaptive mirrors capable of correcting beam aberrations.

Current sources of directed energy also require further research. High-power, solid-state, and diode lasers must be investigated because of their inherent efficiency advantages, their ability to operate without bulky chemical fuels, their potential for operation at shorter wavelengths, and because diode lasers can operate in phased arrays (obvious advantages in pointing and beam-combining).

Finally, further work is required in directed-energy beam propagation. The impressive success of modern low-power adaptive optics techniques must be extended to high-power beams if laser space-strike systems are to reach their full potential.

Projectile Weapons

The approaches mentioned in this paper involving long-range ballistic missiles are already possible—the only thing lacking is the will to proceed. Two technologies are desirable to enhance the effectiveness of such weapons: high-speed (submicrosecond) fusing and high-speed dispersal techniques for submunitions in the terminal phase.

The destructive interaction of hypervelocity projectiles with targets has been investigated by the US military and NASA. These investigations must continue, particularly with regard to hydrodynamic penetrators, if we are to understand how to configure and direct hypervelocity projectiles to achieve optimum effect. Terminal guidance techniques must be improved to enable the use of kinetic energy weapons as true precision-guided weapons.

Space Sortie

The main challenges here lie in propulsion technology (both air breathing and for space) and aerodynamic design for reliable hypersonic flight. Lightweight, high-endurance propulsion systems are needed to operate transatmospheric vehicles (TAV) for long-range sorties. Lightweight, high-temperature materials and high-capacity cooling systems must be developed to form the "skin and bones" of the TAV.

General Considerations

Space-strike weapon systems will not be possible without reliable, affordable access to space. The investigation recommendations of the ***2025*** Space Lift white paper are therefore seconded without reservation in this paper. All the space operations missions—space control, force enhancement, force application, and space support—depend on access to space.[4]

A blind marksman is a contradiction in terms. The space-strike weapon systems of 2025 will depend heavily on America's global information network (see appendix B). In this regard, the following areas of study are as critical for this white paper as they are for the surveillance and reconnaissance and information operations white papers: advanced sensors; data fusion techniques; miniaturization (nanotechnologies and MEMS); secure, reliable, wideband communications; reliable distributed networks (particularly distributed networks of small satellites); advanced, high-speed, high-capacity computers; and the combination of hardware and software technologies which will enable true "artificial intelligence."

The areas recommended for further investigation in this paper must be pursued in full cooperation with industry wherever possible. The days of "fat" defense budgets are long gone—they will not come again in our time. Civilian (domestic and foreign) research dollars will determine the main areas where technology will advance in the twenty-first century. The US military must keep its collective eye on the "main chance," directing its precious and limited research funds where they will have the greatest effect. Anything less would be irresponsible.

Notes

1. "Joint Planning Document FY 1998–2003," 15 December 1995, vol. 4 (Future Capabilities), 2.
2. "Joint Vision 2010 - America's Military: Shaping the Future," a publication of the Joint Staff provided to ***2025*** by AF/XOXS, January 1996, 4.
3. USAF Scientific Advisory Board, *New World Vistas: Air and Space Power for the 21st Century*, summary volume (Washington, D.C.: USAF Scientific Advisory Board, 15 December 1995), 60.
4. Lt Col Henry Baird et al., "Spacelift - Integration of Aerospace Core Competencies," ***2025*** Study (Maxwell AFB, Ala.: Air War College, 1996).

Appendix A

Global Presence

Global presence includes a full range of potential activities ranging from the physical interaction of military forces and targets to the "virtual interaction" between information systems envisioned by the "information warriors." We will explore the idea of global presence by discussing the strengths and weaknesses of the space systems which could yield "global space presence" in 2025. Key technologies will ultimately be identified that link global space presence to a global space-strike capability and to the integrated network of sensors, communications, and information processing required to collect data from any (and every) area of the planet and convert it into information and knowledge in a suitably short time frame. Along the way, we will emphasize the important synergy and interconnectedness between military and commercial space systems in 2025.

Some Important Definitions

Global space presence means providing military space capability, including non-belligerent applications and/or leveraging of information, to deter or compel an actor or affect a situation.[1] Through *global space reach* and *global space power*, multiplied by *global space awareness* and backed up by *sustainment and readiness*, the Air Force can provide an unmatched power projection capability to America's joint force in 2025.[2]

Global space reach includes those activities conducted from space that improve the operational effectiveness of military forces operating in all mediums (space, air, land, sea, subsurface).

Global space power involves the application of the full spectrum of force, physical and virtual, from space on demand to an adversary's means of pursuing the conflict.

Global space awareness is achieved through the integrated, worldwide acquisition, transmission, storage, and processing of information through space to enhance the employment of all military forces.

Readiness and sustainment means providing the ability to mount and support continuous military operations.[3]

Global space presence is a vital capability that can only be achieved by a nation with global space reach, global space power, global space awareness, and a robust readiness and sustainment system. By 2025, a nation that hopes to reap the benefits of great power status must possess global space presence.

In 1996, military space operations are organized to perform four core missions.[4] These mission areas are equally critical to the future success of US military operations at all levels—strategic, operational, and tactical. Space operations have already impacted the combat arms and the combat support elements of all branches of the US military through space reconnaissance, surveillance, and communication. The four core missions focus on enabling or

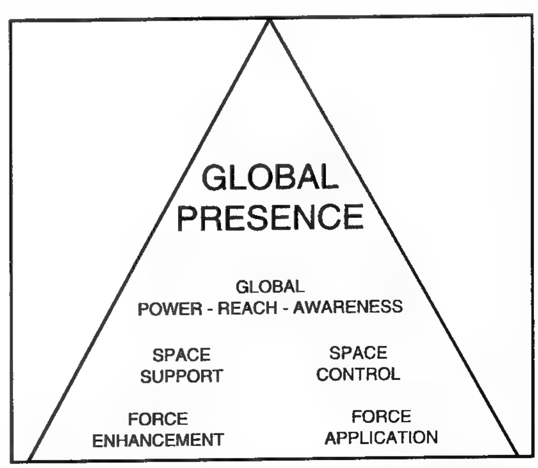

Figure A-1. Space Operations Missions

supporting terrestrial (land, sea, air, and subsurface) military operations with assets operating from space (*force enhancement*); providing freedom of access to and operation in space for friendly forces while denying enemy access (*space-control*); applying force, both physical and virtual, to terrestrial military targets with weapon systems operating from space (*force application*); and conducting launch support and on-orbit military command and control for crucial military space assets (*space support*). Since these mission areas overlap, actual military space operations are broader than any one mission area.[5]

Notes

1. Gen Ronald E. Fogleman, USAF, and Dr Sheila E. Widnall, *Global Presence 1995* (Washington, D.C.: Headquarters USAF, pamphlet, 1995), 3.

2. Air Force Doctrine Document 1, "Air Force Basic Doctrine" (first draft), 15 August 1995, 3.

3. Ibid. Adapted from the discussion documented here.

4. AF Manual 1-1, *Basic Aerospace Doctrine of the United States Air Force*, vol. 2, Essay L (Washington, D.C.: Headquarters USAF, March 1992), 103–11. The missions listed in this paper were adapted from this essay.

5. Maj Thomas A. Torgerson, USAF, "Global Power Through Tactical Flexibly Deployable Space Units" (Maxwell AFB, Ala.: Air University Press, Research Report AU-ARI-93-6, June 1994), 4.

Appendix B

The System-of-Systems

All the systems of the force application system-of-systems must be integrated with all the other systems that interface with it. Onboard (guidance, maneuvering) and off-board (surveillance, some processing) systems all work together as a distributed system-of-systems.

SAT/BDA

The surveillance, acquisition, and tracking/ battle damage assessment (SAT/BDA) requirements fall into the general mission category of force enhancement. The impact of cost constraints and rapidly developing technologies on the Defense Department is moving the initiative in these areas toward the commercial sector. The global positioning system (GPS) is a prominent modern example, with commercial units being bought by the thousands to support Operation Desert Storm. It is very likely, therefore, that a significant amount of surveillance, acquisition, and tracking and battle damage assessment will depend on commercial concepts or commercial assets by 2025. This will be an important factor in two ways. First, a great amount of equipment will be available "off the shelf," and not just in America. Given their high cost, satellite assets will probably be shared, and not always by allies. Who will be in control?

One of the biggest questions in a multinational world, with multinational corporations, is whether we will have access to the information we need. If we do not wish to build duplicate military systems, we must in some way assure ourselves of access to commercial assets while retaining the capability to block an opponent's access. This might be done through treaties or binding business arrangements, but most likely we will need some built-in capability to literally seize control of the necessary portions of shared commercial satellite assets.

The global information network (GIN) of 2025 is the obvious and probably the only affordable place to perform most of the SAT/BDA function. If the military's relatively limited (a matter of funding, not ingenuity) computers, sensors, and dedicated communications are not linked to the GIN, it will be impossible to assemble an accurate "digital picture of the battlefield" in real time. Linkage to the GIN will also provide ready access to rich sources of information unavailable to the modern war fighter. From the perspective of a space-strike weapon system, the availability of multiple views in many sensory bands of each target is an irresistible advantage. This suggests most SAT/BDA functions in 2025 will be performed "off platform" for space-strike weapon systems, making the development of secure, jam-resistant communication links a top priority. Two possibilities have been suggested in this regard: redundant radio frequency (RF) links in many frequency bands, possibly including spread spectrum techniques, and ultrawideband optical communications.[1]

Surveillance

Surveillance can be defined as "systematic observation of aerospace, surface, or subsurface areas, places, persons or things by visual, electronic, photographic or other means."[2] The requirement for this information seems critical today, but in the much faster world of 2025, real-time information will be an absolute imperative. The most survivable and effective way of obtaining real-time surveillance in 2025 will involve networking and fusing sensory data from a wide variety of military, civil, commercial, and even foreign (allied) assets. This exciting possibility awaits technical advances in wideband

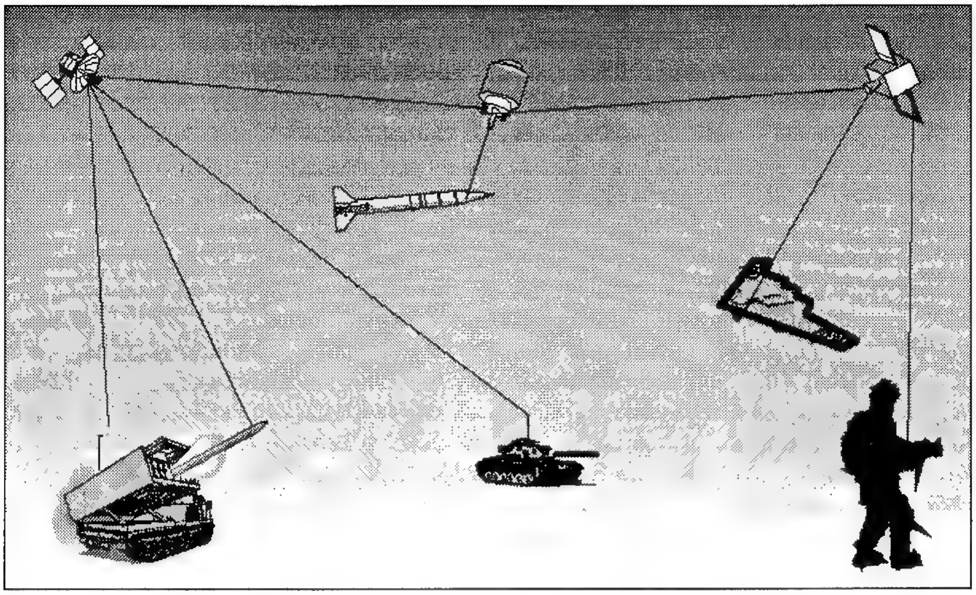

Figure B-2. Battlespace Awareness

communications, wide-area networks, data fusion, and above all a far greater number of fielded sensors. That industry is already moving into the area of high-resolution remote sensing (and especially satellite remote sensing) is obvious from the many recent announcements of commercial satellite imaging systems with a spatial resolution approaching one meter.[3]

In 2025, surveillance systems operating from space will provide the war fighter with indispensable real-time, accurate, preprocessed information. Satellite systems will provide wide spectrum coverage, including visual, infrared, RF, and active radar, for fusing with air-, sea-, and land-based networks of distributed sensors.[4] Fusion and dissemination of surveillance data will be handled by a distributed, wide-area network of computers (probably based on microprocessors in a parallel architecture) linked by the communications system described below in the section on "utilities." The war fighter and his weapon systems, whether air-, sea-, land-, or space-based, will be able to access this information on demand, probably in a graphically oriented format. The *SPACECAST 2020* study is correct in its claim that "a system and architecture must exist to provide a high resolution 'picture' of objects in space, in the air, on the surface, and below the surface—be they concealed, mobile or stationary, animate or inanimate."[5] The real challenge will not be the collection of sufficient data, but its processing into useful, easily digested forms. This will be an ever greater challenge as the amount of types of available information grows between now and 2025.

Acquisition and Targeting

Today "sensors, computers, and communications jointly comprise the essence of targeting."[6] America's main investment in these systems will be commercial by 2025, with a "sprinkling" of important, well-protected (hardening, stealth, CONUS basing, deception), military-only or military-priority assets. This dispersion of assets will be an advantage, since properly designed, distributed systems are much more survivable than centralized, dedicated systems, and because it may be impossible to determine which portion of which physical asset is being used by the military at any one time. Surveillance and

acquisition functions can and should, therefore, be provided by "off platform" distributed systems.

Targeting is a more complex and specialized function. By 2025, automated target acquisition and identification will finally be a reality. The necessary databases and specialized information-processing assets can be made available through the GIN, which will also be linked to any specialized military sensor data that might be required to deal with particularly difficult targets. Automated target acquisition and identification is the subject of intense research today, and many promising approaches are being investigated on conventional supercomputers and clever, proprietary combinations of electronic and optical computers.[7] Commercial satellite remote-sensing systems are already in development with spatial resolutions good enough to identify aircraft, surface ships, land mines, and most smaller vehicles.[8] The results of the primarily off-platform acquisition and targeting functions will then be handed off to the weapon platform, which will provide the tracking and force-application functions.

The *SPACECAST 2020* special study discusses a similar approach. "With appropriate algorithms and beam selection, it is conceivable that the entire sensor constellation could be available for collection all the time. Fusing of the reflected data from a single "taste" [speaking metaphorically] would take place on a central platform, probably in geosynchronous orbit."[9] By 2025, there will be no need for a vulnerable, central collection platform. With the continual miniaturization of computers and electronics, improved network hardware and software, and redundant wideband communication links (both optical and RF) data collection and fusion can and should be shared among a variety of platforms, space- and earth-based.[10] This approach has the enormous advantage of eliminating critical nodes in the US military information system.

Battle Damage Assessment

"BDA has historically been a task of considerable difficulty because the wide range of munitions utilized, the target types attacked and the modes of attack have precluded the application of any single, reliable method."[11] This problem is further complicated by our current strategy of pursuing parallel strategic attacks. By 2025, the solution to this problem will be evident in the "digital picture of the battlefield" assembled from the fused input of myriad sensors of many different types linked wirelessly to the GIN. The very system needed to survey and acquire targets will be used to assess battle damage. The advantages are obvious: cost effectiveness through elimination of redundant sensors and communications, nearly instant assessment of the need for restrike, and economy of force by avoiding the expenditure of unnecessary strikes. Additionally, accomplishing BDA through the GIN would provide instant, automatic feedback to the logistics system of the number and nature of resources expended.[12]

Utilities

During Operation Desert Storm, American and allied forces relied heavily upon space-based systems for navigation, weather information, secure communications, and surveillance support. These and other space assets played a key role in the successful prosecution of the Gulf War. The reliance of the American military on these systems will only grow with time.

The quantity and quality of information that can be gained from the vantage of space enhances the power of existing terrestrial forces, both conventional and unconventional, by providing more and better information ever more rapidly. This rapid movement of information, no matter what the source, will become increasingly essential to all aspects of military operations. The near-real-time capability in communication, navigation, and weather

sensing offered by the proper utilization of space assets and the opportunities they present make these functions critical to the successful military exploitation of space. No space-strike weapon system can operate without the information provided by communications, navigation, and weather systems. That is why these functions are called "utilities" in this paper.

Communications

The US military has become more and more dependent on radio frequency (RF) communications since World War II. Currently, worldwide military communications depend on several constellations of RF communications satellites, including the high frequency (HF) and ultrahigh frequency (UHF) Defense Satellite Communications System (DSCS); the UHF, superhigh frequency (SHF), and extremely high frequency (EHF) Fleet Satellite Communications (FLTSATCOM) and Ultrahigh Frequency Follow-On (UFO) systems; and the secure, jam-resistant UHF, SHF, and EHF-capable Milstar System.[13] Submarine cables, fiber-optic lines, and microwave radio can compete with satellite communication systems only for geographically fixed, wideband service. Satellites are unchallenged in the area of wideband transmissions to mobile terminals, which is precisely the area of greatest need for the military.

During Desert Storm, even the United States's apparently robust satellite communications architecture was overwhelmed—the coalition was forced to lease time on the INTELSAT and SKYNET systems, although the total capability was still "grossly inadequate." The total requirement for voice, data, and video links for the Gulf War ("only" a major regional contingency) was staggering. The worldwide network assembled for Desert Storm involved practically every type of commercial, strategic, and tactical telecommunication equipment available. Unsurprisingly, network management and control was "a sub-optimized, manual process . . . improvised on the spot and under enormous pressure for instant results." It is now generally agreed that "a mix of military and commercial networks is the only way to provide adequate communications support in the future."[14]

The most likely military communications architecture in 2025 is a shared commercial satellite communications system. This system will be based on a large constellation (hundreds or thousands) of small satellites in low earth orbit. Each satellite will be cross-linked to every other satellite with a mixture of truly wideband solid-state laser communication links (digital data rates in excess of 10 gigabytes/second) and high-speed RF back-up links (60 Ghz or greater). Most downlinks will still involve RF technology, since it is simple and inexpensive, but the most demanding traffic will have to be handled optically. Ground stations will be simple and easily relocatable, since each satellite will carry its own formidable computer brain to manage the communications traffic redundantly (the inevitable consequence of the explosion in computer processing speed and capacity). Ground line communications will be nearly nonexistent (too expensive), except for emergency backup systems and a few ultrasecure, jam-resistant communication systems (based on optical fiber as the only way to handle the load). In the world of 2025, every person could contact anyone, anywhere, at any time, if properly equipped.

Navigation

The Navstar GPS satellite navigation system currently provides reliable three-dimensional position information with an accuracy and precision of 16 meters and time with an accuracy of 0.1 microseconds (uncorrupted version).[15] Whenever enough satellites are in view, GPS can even provide velocity and acceleration information. Combined with inexpensive commercial receivers, GPS navigation was critical to the success of coalition forces in the Gulf War. This information is good enough to pilot

cruise missiles hundreds of miles to large targets and to provide targeting coordinates for modern PGMs. It is not good enough for many of the space-strike weapons described earlier in this paper, which require extreme time and position accuracies (a few nanoseconds in time, centimeters in position) to be fully effective.

The *SPACECAST 2020* special study recognized the need for an improved navigation system in their Super GPS white paper.[16] In 2025, such a system will be owned and controlled by civilian organizations—the Federal Aviation Agency is assuming greater control over the existing GPS constellation every day. The most likely candidates for control of the Super GPS system of 2025 are the Federal Aviation Agency (or more likely an internationalized successor) and one or more international commercial concerns. The system, based on a larger constellation of small satellites in LEO for increased coverage and on-orbit redundancy, will certainly be more accurate and precise. It is difficult to predict where the constantly evolving commercial demand for three-dimensional positioning information will be in 2025, but it is probably safe to forecast performance measured in feet (large fractions of a meter). Military demands in excess of this will be handled either by small military-owned payloads on the commercial satellites or by a small military-funded augmentation to the commercial constellation.

Weather

Military commanders have always needed timely, accurate weather information to mount successful campaigns. This need will be even more urgent in 2025, when optimal use of all forces will require real-time information on *all* battlefield conditions. Additionally, space-strike weapons need a mixture of space weather data and battlefield environmental data to be effective. Space-based HPMW beams can be disrupted by intense solar winds. Space-strike lasers are dispersed by water clouds and battlefield dust and smoke. Hypervelocity kinetic energy weapons must have good information concerning the state of the atmosphere to reach the proper spot on the target.

Industry is developing smaller and higher performance remote sensors with every passing day.[17] Commercial demand and commercial funding is already outstripping the military's capabilities (everyone needs to know about the weather). The National Oceanic and Atmospheric Administration is already taking charge of what were once military-controlled weather satellites.[18] These trends strongly suggest that long before 2025, weather-related remote sensing will be entirely controlled by industry. The commercially controlled weather monitoring and prediction system in 2025 will probably depend on a sophisticated suite of ultraminiaturized electronics and sensors operating as a secondary payload on a LEO satellite communications constellation, thereby taking advantage of existing down- and cross-links. A few small weather satellites will still be parked at geosynchronous earth orbit (GEO) to take advantage of its larger-scale view of earth and to monitor "space weather" at a distance from the less-placid LEO environment. While most requirements for weather-related information in a military theater of operations will be handled by this mix of LEO and GEO weather satellites, some detailed weapon system requirements for data on surface conditions will still have to be handled by a network of ground-based sensors connected to the global information network.

Notes

1. ***2025*** Concept no. 900522, "Space-Based AI-Driven Intelligence Master Mind"; ***2025*** Concept no. 900283, "Information Supremacy"; ***2025*** Concept no. 900335, "Worldwide Military Cellular Phone System"; ***2025*** Concept no. 900585, "Global Location & Secure Comm," ***2025*** concepts database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

2. Data Fusion Lexicon, Data Fusion Sub-Panel of the Joint Directors of Laboratories, "Technical Panel for C^3," 11.

3. Maj James G. Lee, USAF, "Counterspace Operations for Information Dominance" (Maxwell AFB, Ala.: Air University Press, October 1994), 14–16.

4. ***2025*** Concept no. 900414, "Artificial Intelligence: A New Aircrew Member in Tomorrow's Combat"; ***2025*** Concept no. 900263, "The All Seeing Warrior," ***2025*** concepts database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

5. *SPACECAST 2020*, "Global Surveillance, Reconnaissance, and Targeting System"(Maxwell AFB, Ala.: Air University Press, 1994).

6. Briefing by Dr Lowell Wood at Air War College, subject: Special Projects at Lawrence Livermore National Laboratory, 27 October 1993, slide 7.

7. Information obtained from senior industry personnel under the promise of nonattribution.

8. Maj James G. Lee, USAF, "Counterspace Operations for Information Dominance," 15. See Table 5.

9. *SPACECAST 2020*, "Global Surveillance, Reconnaissance, and Targeting System."

10. ***2025*** Concept no. 900370, "Molecular Manufacturing and Nanotechnology"; ***2025*** Concept no. 900518, "Electronic Grid - Throwaway Sensors"; ***2025*** Concept no. 200023, "Surveillance Swarm"; ***2025*** Concept no. 900231, "Gnat Robot Threat Detectors," ***2025*** concepts database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

11. Carlo Kopp, "Air Warfare Applications of Laser Remote Sensing" (Fairbairn, Australia: Air Power Studies Centre), 3.

12. ***2025*** Concept no. 900672, "Integrated Logistical Battlespace Sustainment," ***2025*** concepts database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

13. Capt Kimberly M. Walker, USAF, "Space Operations Training Course - Chapter 9: Introduction to Communications Satellites" (Peterson AFB, Colo.: 1994), 134–48.

14. Alan Campan, *The First Information War* (Fairfax, Va.: AFCEA International Press, 1994), 18, 21.

15. Capt Kimberly M. Walker, Capt, USAF, and Capt Tery L. Donelson, Space Operations Training Course - Chap 10. Navstar Global Positioning System" (Peterson AFB, Colo.: 1994), 152.

16. *SPACECAST 2020*, "Operational Analysis" (Maxwell AFB, Ala.: Air University Press, 1994), 35.

17. Sarah L Cain, "Eyes in the Sky: Satellite Imagery Blasts Off," *Photonics Spectra*, October 1995, 90.

18. Conversations with Air Force colonel Chuck Thompson, Air War College Space Chair, December 4 1995.

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Weather as a Force Multiplier: Owning the Weather in 2025

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Executive Summary

In 2025, US aerospace forces can "own the weather" by capitalizing on emerging technologies and focusing development of those technologies to war-fighting applications. Such a capability offers the war fighter tools to shape the battlespace in ways never before possible. It provides opportunities to impact operations across the full spectrum of conflict and is pertinent to all possible futures. The purpose of this paper is to outline a strategy for the use of a future weather-modification system to achieve military objectives rather than to provide a detailed technical road map.

A high-risk, high-reward endeavor, weather modification offers a dilemma not unlike the splitting of the atom. While some segments of society will always be reluctant to examine controversial issues such as weather modification, the tremendous military capabilities that could result from this field are ignored at our own peril. From enhancing friendly operations or disrupting those of the enemy via small-scale tailoring of natural weather patterns to complete dominance of global communications and counterspace control, weather modification offers the war fighter a wide range of possible options to defeat or coerce an adversary. Some of the potential capabilities a weather-modification system could provide to a war-fighting commander in chief (CINC) are listed in table 1.

Technology advancements in five major areas are necessary for an integrated weather-modification capability: (1) advanced nonlinear modeling techniques, (2) computational capability, (3) information gathering and transmission, (4) a global sensor array, and (5) weather intervention techniques. Some intervention tools exist today and others may be developed and refined in the future.

Current technologies that will mature over the next 30 years will offer anyone who has the necessary resources the ability to modify weather patterns and their corresponding effects, at least on the local scale. Current demographic, economic, and environmental trends will create global stresses that provide the impetus necessary for many countries or groups to turn this weather-modification ability into a capability.

In the United States, weather modification will likely become a part of national security policy with both domestic and international applications. Our government will pursue such a policy, depending on its interests, at various levels. These levels could include unilateral actions, participation in a security framework such as NATO, membership in an international organization such as the UN, or participation in a coalition. Assuming that in 2025 our national security strategy includes weather modification, its use in our national military strategy will naturally follow. Besides the significant benefits an operational capability would

Table 1

Operational Capabilities Matrix

DEGRADE ENEMY FORCES	ENHANCE FRIENDLY FORCES
Precipitation Enhancement – Flood Lines of Communication – Reduce PGM/Recce Effectiveness – Decrease Comfort Level/Morale	**Precipitation Avoidance** – Maintain/Improve LOC – Maintain Visibility – Maintain Comfort Level/Morale
Storm Enhancement – Deny Operations	**Storm Modification** – Choose Battlespace Environment
Precipitation Denial – Deny Fresh Water — Induce Drought	**Space Weather** – Improve Communication Reliability – Intercept Enemy Transmissions – Revitalize Space Assets
Space Weather – Disrupt Communications/Radar – Disable/Destroy Space Assets	**Fog and Cloud Generation** – Increase Concealment
Fog and Cloud Removal – Deny Concealment – Increase Vulnerability to PGM/Recce	**Fog and Cloud Removal** – Maintain Airfield Operations – Enhance PGM Effectiveness
Detect Hostile Weather Activities	**Defend against Enemy Capabilities**

provide, another motivation to pursue weather modification is to deter and counter potential adversaries.

In this paper we show that appropriate application of weather modification can provide battlespace dominance to a degree never before imagined. In the future, such operations will enhance air and space superiority and provide new options for battlespace shaping and battlespace awareness.[1] "The technology is there, waiting for us to pull it all together";[2] in 2025 we can "Own the Weather."

Notes

1. The weather-modification capabilities described in this paper are consistent with the operating environments and missions relevant for aerospace forces in 2025 as defined by AF/LR, a long-range planning office reporting to the CSAF [based on AF/LR PowerPoint briefing "Air and Space Power Framework for Strategy Development (jda-2lr.ppt)]."

2. Gen Gordon R. Sullivan, "Moving into the 21st Century: America's Army and Modernization," *Military Review*, July 1993, quoted in Mary Ann Seagraves and Richard Szymber, "Weather a Force Multiplier," *Military Review*, November/December 1995, 75.

Chapter 1

Introduction

Scenario: Imagine that in 2025 the US is fighting a rich, but now consolidated, politically powerful drug cartel in South America. The cartel has purchased hundreds of Russian- and Chinese-built fighters that have successfully thwarted our attempts to attack their production facilities. With their local numerical superiority and interior lines, the cartel is launching more than 10 aircraft for every one of ours. In addition, the cartel is using the French *system probatoire d' observation de la terre* (SPOT) positioning and tracking imagery systems, which in 2025 are capable of transmitting near-real-time, multispectral imagery with one-meter resolution. The US wishes to engage the enemy on an uneven playing field in order to exploit the full potential of our aircraft and munitions.

Meteorological analysis reveals that equatorial South America typically has afternoon thunderstorms on a daily basis throughout the year. Our intelligence has confirmed that cartel pilots are reluctant to fly in or near thunderstorms. Therefore, our weather force support element (WFSE), which is a part of the commander in chief's (CINC) air operations center (AOC), is tasked to forecast storm paths and trigger or intensify thunderstorm cells over critical target areas that the enemy must defend with their aircraft. Since our aircraft in 2025 have all-weather capability, the thunderstorm threat is minimal to our forces, and we can effectively and decisively control the sky over the target.

The WFSE has the necessary sensor and communication capabilities to observe, detect, and act on weather-modification requirements to support US military objectives. These capabilities are part of an advanced battle area system that supports the war-fighting CINC. In our scenario, the CINC tasks the WFSE to conduct storm intensification and concealment operations. The WFSE models the atmospheric conditions to forecast, with 90 percent confidence, the likelihood of successful modification using airborne cloud generation and seeding.

In 2025, uninhabited aerospace vehicles (UAV) are routinely used for weather-modification operations. By cross-referencing desired attack times with wind and thunderstorm forecasts and the SPOT satellite's projected orbit, the WFSE generates mission profiles for each UAV. The WFSE guides each UAV using near-real-time information from a networked sensor array.

Prior to the attack, which is coordinated with forecasted weather conditions, the UAVs begin cloud generation and seeding operations. UAVs disperse a cirrus shield to deny enemy visual and infrared (IR) surveillance. Simultaneously, microwave heaters create localized scintillation to disrupt active sensing via synthetic aperture radar (SAR) systems such as the commercially available Canadian search and rescue satellite-aided tracking (SARSAT) that will be widely available in 2025. Other cloud seeding operations cause a developing thunderstorm to intensify over the target, severely limiting the enemy's capability to defend. The WFSE monitors the entire operation in real-time and notes the successful completion of another very important but routine weather-modification mission.

This scenario may seem far-fetched, but by 2025 it is within the realm of possibility. The next chapter explores the reasons for weather modification, defines the scope, and examines trends that will make it possible in the next 30 years.

Chapter 2

Required Capability

Why Would We Want to Mess with the Weather?

According to Gen Gordon Sullivan, former Army chief of staff, "As we leap technology into the 21st century, we will be able to see the enemy day or night, in any weather—and go after him relentlessly."[1] A global, precise, real-time, robust, systematic weather-modification capability would provide war-fighting CINCs with a powerful force multiplier to achieve military objectives. Since weather will be common to all possible futures, a weather-modification capability would be universally applicable and have utility across the entire spectrum of conflict. The capability of influencing the weather even on a small scale could change it from a force degrader to a force multiplier.

People have always wanted to be able to do something about the weather. In the US, as early as 1839, newspaper archives tell of people with serious and creative ideas on how to make rain.[2] In 1957, the president's advisory committee on weather control explicitly recognized the military potential of weather modification, warning in their report that it could become a more important weapon than the atom bomb.[3]

However, controversy since 1947 concerning the possible legal consequences arising from the deliberate alteration of large storm systems meant that little future experimentation could be conducted on storms which had the potential to reach land.[4] In 1977, the UN General Assembly adopted a resolution prohibiting the hostile use of environmental modification techniques. The resulting "Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Technique (ENMOD)" committed the signatories to refrain from any military or other hostile use of weather modification which could result in widespread, long-lasting, or severe effects.[5] While these two events have not halted the pursuit of weather-modification research, they have significantly inhibited its pace and the development of associated technologies, while producing a primary focus on suppressive versus intensification activities.

The influence of the weather on military operations has long been recognized. During World War II, Eisenhower said,

> [i]n Europe bad weather is the worst enemy of the air [operations]. Some soldier once said, "The weather is always neutral." Nothing could be more untrue. Bad weather is obviously the enemy of the side that seeks to launch projects requiring good weather, or of the side possessing great assets, such as strong air forces, which depend upon good weather for effective operations. If really bad weather should endure permanently, the Nazi would need nothing else to defend the Normandy coast![6]

The impact of weather has also been important in more recent military operations. A significant number of the air sorties into Tuzla during the initial deployment supporting the Bosnian peace operation aborted due to weather. During Operation Desert Storm, Gen Buster C. Glosson asked his weather officer to tell him which targets would be clear in 48 hours for inclusion in the air tasking order (ATO).[7] But current forecasting capability is only 85 percent accurate for no more than 24 hours, which doesn't adequately meet the needs of the ATO planning cycle. Over 50 percent of the F-117 sorties weather aborted over their targets and A-10s only flew 75 of 200 scheduled close air support (CAS) missions due to low cloud cover during the first two days of the campaign.[8] The application of weather-modification technology to clear a hole over the targets

long enough for F-117s to attack and place bombs on target or clear the fog from the runway at Tuzla would have been a very effective force multiplier. Weather modification clearly has potential for military use at the operational level to reduce the elements of fog and friction for friendly operations and to significantly increase them for the enemy.

What Do We Mean by "Weather Modification"?

Today, weather modification is the alteration of weather phenomena over a limited area for a limited period of time.[9] Within the next three decades, the concept of weather modification could expand to include the ability to shape weather patterns by influencing their determining factors.[10] Achieving such a highly accurate and reasonably precise weather-modification capability in the next 30 years will require overcoming some challenging but not insurmountable technological and legal hurdles.

Technologically, we must have a solid understanding of the variables that affect weather. We must be able to model the dynamics of their relationships, map the possible results of their interactions, measure their actual real-time values, and influence their values to achieve a desired outcome. Society will have to provide the resources and legal basis for a mature capability to develop. How could all of this happen? The following notional scenario postulates how weather modification might become both technically feasible and socially desirable by 2025.

Between now and 2005, technological advances in meteorology and the demand for more precise weather information by global businesses will lead to the successful identification and parameterization of the major variables that affect weather. By 2015, advances in computational capability, modeling techniques, and atmospheric information tracking will produce a highly accurate and reliable weather prediction capability, validated against real-world weather. In the following decade, population densities put pressure on the worldwide availability and cost of food and usable water. Massive life and property losses associated with natural weather disasters become increasingly unacceptable. These pressures prompt governments and/or other organizations who are able to capitalize on the technological advances of the previous 20 years to pursue a highly accurate and reasonably precise weather-modification capability. The increasing urgency to realize the benefits of this capability stimulates laws and treaties, and some unilateral actions, making the risks required to validate and refine it acceptable. By 2025, the world, or parts of it, are able to shape local weather patterns by influencing the factors that affect climate, precipitation, storms and their effects, fog, and near space. These highly accurate and reasonably precise civil applications of weather-modification technology have obvious military implications. This is particularly true for aerospace forces, for while weather may affect all mediums of operation, it operates in ours.

The term *weather modification* may have negative connotations for many people, civilians and military members alike. It is thus important to define the scope to be considered in this paper so that potential critics or proponents of further research have a common basis for discussion.

In the broadest sense, weather modification can be divided into two major categories: suppression and intensification of weather patterns. In extreme cases, it might involve the creation of completely new weather patterns, attenuation or control of severe storms, or even alteration of global climate on a far-reaching and/or long-lasting scale. In the mildest and least controversial cases it may consist of inducing or suppressing precipitation, clouds, or fog for short times over a small-scale region. Other low-intensity applications might include the alteration and/or use of near space as a medium to

enhance communications, disrupt active or passive sensing, or other purposes. In conducting the research for this study, the broadest possible interpretation of weather modification was initially embraced, so that the widest range of opportunities available for our military in 2025 were thoughtfully considered. However, for several reasons described below, *this paper focuses primarily on localized and short-term forms of weather modification and how these could be incorporated into war-fighting capability. The primary areas discussed include generation and dissipation of precipitation, clouds, and fog; modification of localized storm systems; and the use of the ionosphere and near space for space control and communications dominance. These applications are consistent with CJCSI 3810.01, "Meteorological and Oceanographic Operations."*[11]

Extreme and controversial examples of weather modification—creation of made-to-order weather, large-scale climate modification, creation and/or control (or "steering") of severe storms, and so forth—were researched as part of this study but receive only brief mention here because, in the authors' judgment, the technical obstacles preventing their application appear insurmountable within 30 years.[12] If this were not the case, such applications would have been included in this report as potential military options, despite their controversial and potentially malevolent nature and their inconsistency with standing UN agreements to which the US is a signatory.

On the other hand, the weather-modification applications proposed in this report range from technically proven to potentially feasible. They are similar, however, in that none are currently employed or envisioned for employment by our operational forces. They are also similar in their potential value for the war fighter of the future, as we hope to convey in the following chapters. A notional integrated system that incorporates weather-modification tools will be described in the next chapter; how those tools might be applied are then discussed within the framework of the Concept of Operations in chapter 4.

Notes

1. Gen Gordon R. Sullivan, "Moving into the 21st Century: America's Army and Modernization," *Military Review*, July 1993, quoted in Mary Ann Seagraves and Richard Szymber, "Weather a Force Multiplier," *Military Review*, November/December 1995, 75.

2. Horace R. Byers, "History of Weather Modification," in Wilmot N. Hess, ed. *Weather and Climate Modification* (New York: John Wiley & Sons, 1974), 4.

3. William B. Meyer, "The Life and Times of US Weather: What Can We Do about It?" *American Heritage* 37, no. 4 (June/July 1986): 48.

4. Byers, 13.

5. US Department of State, *The Department of State Bulletin* 74, no. 1981 (13 June 1977): 10.

6. Dwight D. Eisenhower, "Crusade in Europe," quoted in John F. Fuller, *Thor's Legions* (Boston: American Meteorology Society, 1990), 67.

7. Interview of Lt Col Gerald F. Riley, Staff Weather Officer to CENTCOM OIC of CENTAF Weather Support Force and Commander of 3d Weather Squadron, in "Desert Shield/Desert Storm Interview Series," by Dr William E. Narwyn, AWS Historian, 29 May 1991.

8. Thomas A. Keaney and Eliot A. Cohen, *Gulf War Air Power Survey Summary Report* (Washington, D.C.: Government Printing Office, 1993), 172.

9. Herbert S. Appleman, *An Introduction to Weather Modification* (Scott AFB, Ill.: Air Weather Service/MAC, September 1969), 1.

10. William Brown, "Mathematicians Learn How to Tame Chaos," *New Scientist*, 30 May 1992, 16.

11. CJCSI 3810.01, *Meteorological and Oceanographic Operations*, 10 January 1995. This CJCS Instruction establishes policy and assigns responsibilities for conducting meteorological and oceanographic operations. It also defines the terms *widespread*, *long-lasting*, and *severe* in order to identify those activities that US forces are prohibited from conducting under the terms of the UN Environmental Modification Convention. Widespread is defined as encompassing an area on the scale of several hundred km; long-lasting means lasting for a period of months, or approximately a season; and severe involves serious or significant disruption or harm to human life, natural and economic resources, or other assets.

12. Concern about the unintended consequences of attempting to "control" the weather is well justified. Weather is a classic example of a chaotic system (i.e., a system that never exactly repeats itself). A chaotic system is also extremely sensitive: minuscule differences in conditions greatly affect outcomes. According to Dr Glenn James, a widely published chaos expert, technical advances may provide a means to predict *when* weather transitions will occur and the magnitude of the inputs required to cause those transitions; however, it will never be possible to precisely predict changes that occur as a result of our inputs. The chaotic nature of weather also limits our ability to make accurate long-range forecasts. The

renowned physicist Edward Teller recently presented calculations he performed to determine the long-range weather forecasting improvement that would result from a satellite constellation providing continuous atmospheric measurements over a 1 km^2 grid worldwide. Such a system, which is currently cost-prohibitive, would only improve long-range forecasts from the current five days to approximately 14 days. Clearly, there are definite physical limits to mankind's ability to control nature, but the extent of those physical limits remains an open question. Sources: G. E. James, "Chaos Theory: The Essentials for Military Applications," in *ACSC Theater Air Campaign Studies Coursebook*, AY96, 8 (Maxwell AFB, Ala.: Air University Press, 1995), 1–64. The Teller calculations are cited in Reference 49 of this source.

Chapter 3

System Description

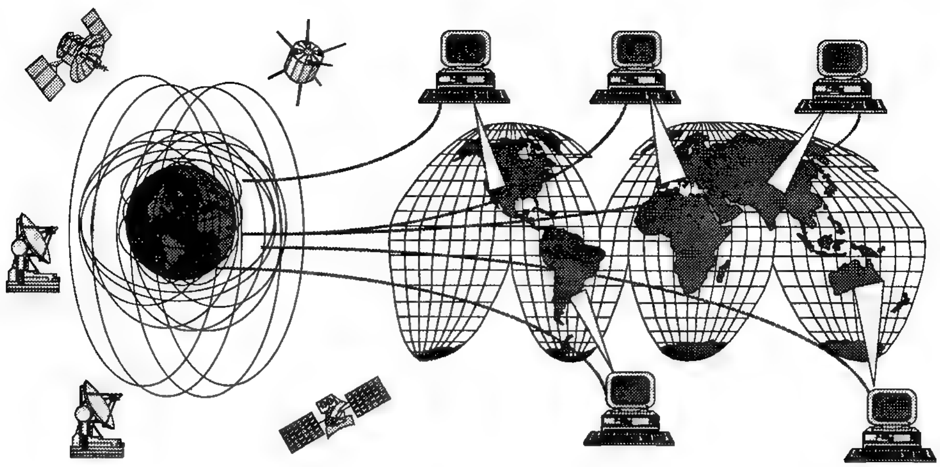
Our vision is that by 2025 the military could influence the weather on a mesoscale (<200 km^2) or microscale (immediate local area) to achieve operational capabilities such as those listed in table 1. The capability would be the synergistic result of a system consisting of (1) highly trained weather force specialists (WFS) who are members of the CINC's weather force support element (WFSE); (2) access ports to the global weather network (GWN), where worldwide weather observations and forecasts are obtained near-real-time from civilian and military sources; (3) a dense, highly accurate local area weather sensing and communication system; (4) an advanced computer local area weather-modification modeling and prediction capability within the area of responsibility (AOR); (5) proven weather-modification intervention technologies; and (6) a feedback capability.

The Global Weather Network

The GWN is envisioned to be an evolutionary expansion of the current military and civilian worldwide weather data network. By 2025, it will be a super high-speed, expanded bandwidth, communication network filled with near-real-time weather observations taken from a denser and more accurate worldwide observation network resulting from highly improved ground, air, maritime, and space sensors. The network will also provide access to forecast centers around the world where sophisticated, tailored forecast and data products, generated from weather prediction models (global, regional, local, specialized, etc.) based on the latest nonlinear mathematical techniques are made available to GWN customers for near-real-time use.

By 2025, we envision that weather prediction models, in general, and mesoscale weather-modification models, in particular, will be able to emulate all-weather producing variables, along with their interrelated dynamics, and prove to be highly accurate in stringent measurement trials against empirical data. The brains of these models will be advanced software and hardware capabilities which can rapidly ingest trillions of environmental data points, merge them into usable databases, process the data through the weather prediction models, and disseminate the weather information over the GWN in near real time.[1] This network is depicted schematically in figure 3-1.

Evidence of the evolving future weather modeling and prediction capability as well as the GWN can be seen in the National Oceanic and Atmospheric Administration's (NOAA) 1995–2005 strategic plan. It includes program elements to "advance short-term warning and forecast services, implement seasonal to inter-annual climate forecasts, and predict and assess decadal to centennial change;"[2] it does not, however, include plans for weather-modification modeling or modification technology development. NOAA's plans include extensive data gathering programs such as Next Generation Radar (NEXRAD) and Doppler weather surveillance systems deployed throughout the US. Data from these sensing systems feed into over 100 forecast centers for processing by the Advanced Weather Interactive Processing System (AWIPS), which will provide data communication, processing, and display capabilities for extensive forecasting. In addition, NOAA has leased a Cray C90 supercomputer capable of performing over 1.5×10^{10} operations per second that has already been used to run a Hurricane Prediction System.[3]



Source: Microsoft Clipart Gallery © 1995 with courtesy from Microsoft.

Figure 3-1. Global Weather Network

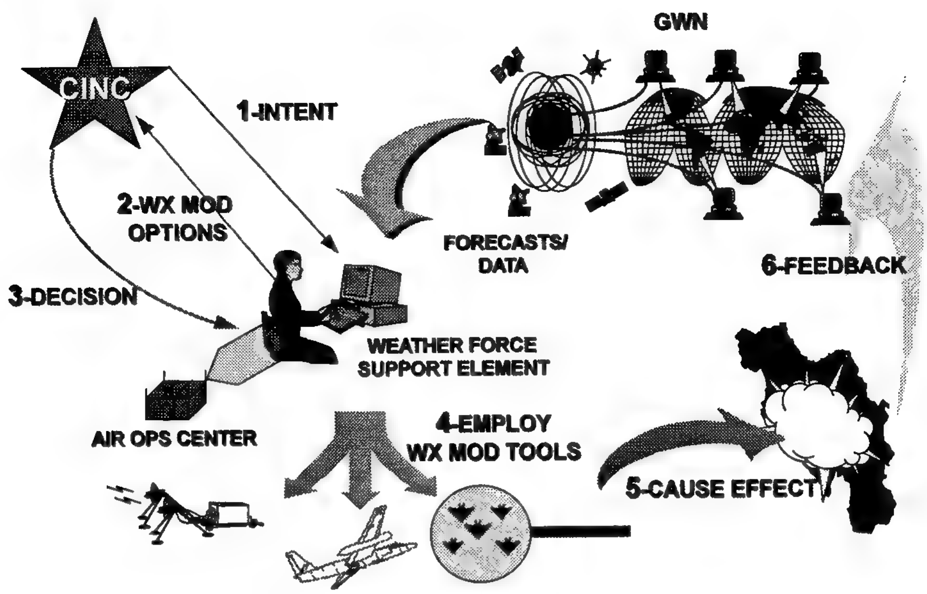
Applying Weather Modification to Military Operations

How will the military, in general, and the USAF, in particular, manage and employ a weather-modification capability? We envision this will be done by the weather force support element, whose primary mission would be to support the war-fighting CINCs with weather-modification options, in addition to current forecasting support. Although the WFSE could operate anywhere as long as it has access to the GWN and the system components already discussed, it will more than likely be a component within the AOC or its 2025-equivalent. With the CINC's intent as guidance, the WFSE formulates weather-modification options using information provided by the GWN, local weather data network, and weather-modification forecast model. The options include range of effect, probability of success, resources to be expended, the enemy's vulnerability, and risks involved. The CINC chooses an effect based on these inputs, and the WFSE then implements the chosen course, selecting the right modification tools and employing them to achieve the desired effect. Sensors detect the change and feed data on the new weather pattern to the modeling system which updates its forecast accordingly. The WFSE checks the effectiveness of its efforts by pulling down the updated current conditions and new forecast(s) from the GWN and local weather data network, and plans follow-on missions as needed. This concept is illustrated in figure 3-2.

WFSE personnel will need to be experts in information systems and well schooled in the arts of both offensive and defensive information warfare. They would also have an in-depth understanding of the GWN and an appreciation for how weather modification could be employed to meet a CINC's needs.

Because of the nodal web nature of the GWN, this concept would be very flexible. For instance, a WFSE could be assigned to each theater to provide direct support to the CINC. The system would also be survivable, with multiple nodes connected to the GWN.

A product of the information age, this system would be most vulnerable to information warfare. Each WFSE would need the most current defensive and



Source: Microsoft Clipart Gallery © 1995 with courtesy from Microsoft.

Figure 3-2. The Military System for Weather-Modification Operations

offensive information capabilities available. Defensive abilities would be necessary for survival. Offensive abilities could provide spoofing options to create virtual weather in the enemy's sensory and information systems, making it more likely for them to make decisions producing results of our choosing rather than theirs. It would also allow for the capability to mask or disguise our weather-modification activities.

Two key technologies are necessary to meld an integrated, comprehensive, responsive, precise, and effective weather-modification system. Advances in the science of chaos are critical to this endeavor. Also key to the feasibility of such a system is the ability to model the extremely complex nonlinear system of global weather in ways that can accurately predict the outcome of changes in the influencing variables. Researchers have already successfully controlled single variable nonlinear systems in the lab and hypothesize that current mathematical techniques and computer capacity could handle systems with up to five variables. Advances in these two areas would make it feasible to affect regional weather patterns by making small, continuous nudges to one or more influencing factors. Conceivably, with enough lead time and the right conditions, you could get "made-to-order" weather.[4]

Developing a true weather-modification capability will require various intervention tools to adjust the appropriate meteorological parameters in predictable ways. It is this area that must be developed by the military based on specific required capabilities such as those listed in table 1. Such a system would contain a sensor array and localized battle area data net to provide the fine level of resolution required to detect intervention effects and provide feedback. This net would include ground, air, maritime, and space sensors as well as human observations in order to ensure the reliability and responsiveness of the system, even in the event of enemy countermeasures. It would also include specific intervention tools and

technologies, some of which already exist and others which must be developed. Some of these proposed tools are described in the following chapter titled "Concept of Operations." The total weather-modification process would be a real-time loop of continuous, appropriate, measured interventions, and feedback capable of producing desired weather behavior.

Notes

1. SPACECAST 2020, *Space Weather Support for Communications*, white paper G (Maxwell AFB, Ala.: Air War College/2020, 1994).
2. Rear Adm Sigmund Petersen, "NOAA Moves toward the 21st Century," *The Military Engineer* 20, no. 571 (June–July 1995): 44.
3. Ibid.
4. William Brown, "Mathematicians Learn How to Tame Chaos," *New Scientist*, 30 May 1992, 16.

Chapter 4

Concept of Operations

The essential ingredient of the weather-modification system is the set of intervention techniques used to modify the weather. The number of specific intervention methodologies is limited only by the imagination, but with few exceptions they involve infusing either energy or chemicals into the meteorological process in the right way, at the right place and time. The intervention could be designed to modify the weather in a number of ways, such as influencing clouds and precipitation, storm intensity, climate, space, or fog.

Precipitation

For centuries man has desired the ability to influence precipitation at the time and place of his choosing. Until recently, success in achieving this goal has been minimal; however, a new window of opportunity may exist resulting from development of new technologies and an increasing world interest in relieving water shortages through precipitation enhancement. Consequently, we advocate that the DOD explore the many opportunities (and also the ramifications) resulting from development of a capability to influence precipitation or conducting "selective precipitation modification." Although the capability to influence precipitation over the long term (i.e., for more than several days) is still not fully understood. By 2025 we will certainly be capable of increasing or decreasing precipitation over the short term in a localized area.

Before discussing research in this area, it is important to describe the benefits of such a capability. While many military operations may be influenced by precipitation, ground mobility is most affected. Influencing precipitation could prove useful in two ways. First, enhancing precipitation could decrease the enemy's trafficability by muddying terrain, while also affecting their morale. Second, suppressing precipitation could increase friendly trafficability by drying out an otherwise muddied area.

What is the possibility of developing this capability and applying it to tactical operations by 2025? Closer than one might think. Research has been conducted in precipitation modification for many years, and an aspect of the resulting technology was applied to operations during the Vietnam War.[1] These initial attempts provide a foundation for further development of a true capability for selective precipitation modification.

Interestingly enough, the US government made a conscious decision to stop building upon this foundation. As mentioned earlier, international agreements have prevented the US from investigating weather-modification operations that could have widespread, long-lasting, or severe effects. However, possibilities do exist (within the boundaries of established treaties) for using localized precipitation modification over the short term, with limited and potentially positive results.

These possibilities date back to our own previous experimentation with precipitation modification. As stated in an article appearing in the *Journal of Applied Meteorology*,

> [n]early all the weather-modification efforts over the last quarter century have been aimed at producing changes on the cloud scale through exploitation of the saturated vapor pressure difference between ice and water. This is not to be criticized but it is time we also consider the feasibility of weather modification on other time-space scales and with other physical hypotheses.[2]

This study by William M. Gray and others investigated the hypothesis that "significant

beneficial influences can be derived through judicious exploitation of the solar absorption potential of carbon black dust."[3] The study ultimately found that this technology could be used to enhance rainfall on the mesoscale, generate cirrus clouds, and enhance cumulonimbus (thunderstorm) clouds in otherwise dry areas.

The technology can be described as follows. Just as a black tar roof easily absorbs solar energy and subsequently radiates heat during a sunny day, carbon black also readily absorbs solar energy. When dispersed in microscopic or "dust" form in the air over a large body of water, the carbon becomes hot and heats the surrounding air, thereby increasing the amount of evaporation from the body of water below. As the surrounding air heats up, parcels of air will rise and the water vapor contained in the rising air parcel will eventually condense to form clouds. Over time the cloud droplets increase in size as more and more water vapor condenses, and eventually they become too large and heavy to stay suspended and will fall as rain or other forms of precipitation.[4] The study points out that this precipitation enhancement technology would work best "upwind from coastlines with onshore flow." Lake-effect snow along the southern edge of the Great Lakes is a naturally occurring phenomenon based on similar dynamics.

Can this type of precipitation enhancement technology have military applications? Yes, if the right conditions exist. For example, if we are fortunate enough to have a fairly large body of water available upwind from the targeted battlefield, carbon dust could be placed in the atmosphere over that water. Assuming the dynamics are supportive in the atmosphere, the rising saturated air will eventually form clouds and rainshowers downwind over the land.[5] While the likelihood of having a body of water located upwind of the battlefield is unpredictable, the technology could prove enormously useful under the right conditions. Only further experimentation will determine to what degree precipitation enhancement can be controlled.

If precipitation enhancement techniques are successfully developed and the right natural conditions also exist, we must also be able to disperse carbon dust into the desired location. Transporting it in a completely controlled, safe, cost-effective, and reliable manner requires innovation. Numerous dispersal techniques have already been studied, but the most convenient, safe, and cost-effective method discussed is the use of afterburner-type jet engines to generate carbon particles while flying through the targeted air. This method is based on injection of liquid hydrocarbon fuel into the afterburner's combustion gases. This direct generation method was found to be more desirable than another plausible method (i.e., the transport of large quantities of previously produced and properly sized carbon dust to the desired altitude).

The carbon dust study demonstrated that small-scale precipitation enhancement is possible and has been successfully verified under certain atmospheric conditions. Since the study was conducted, no known military applications of this technology have been realized. However, we can postulate how this technology might be used in the future by examining some of the delivery platforms conceivably available for effective dispersal of carbon dust or other effective modification agents in the year 2025.

One method we propose would further maximize the technology's safety and reliability, by virtually eliminating the human element. To date, much work has been done on UAVs which can closely (if not completely) match the capabilities of piloted aircraft. If this UAV technology were combined with stealth and carbon dust technologies, the result could be a UAV aircraft invisible to radar while en route to the targeted area, which could spontaneously create carbon dust in any location. However, minimizing the number of UAVs

required to complete the mission would depend upon the development of a new and more efficient system to produce carbon dust by a follow-on technology to the afterburner-type jet engines previously mentioned. In order to effectively use stealth technology, this system must also have the ability to disperse carbon dust while minimizing (or eliminating) the UAV's infrared heat source.

In addition to using stealth UAV and carbon dust absorption technology for precipitation enhancement, this delivery method could also be used for precipitation suppression. Although the previously mentioned study did not significantly explore the possibility of cloud seeding for precipitation suppression, this possibility does exist. If clouds were seeded (using chemical nuclei similar to those used today or perhaps a more effective agent discovered through continued research) before their downwind arrival to a desired location, the result could be a suppression of precipitation. In other words, precipitation could be "forced" to fall before its arrival in the desired territory, thereby making the desired territory "dry." The strategic and operational benefits of doing this have previously been discussed.

Fog

In general, successful fog dissipation requires some type of heating or seeding process. Which technique works best depends on the type of fog encountered. In simplest terms, there are two basic types of fog—cold and warm. Cold fog occurs at temperatures below 32°F. The best-known dissipation technique for cold fog is to seed it from the air with agents that promote the growth of ice crystals.[6]

Warm fog occurs at temperatures above 32°F and accounts for 90 percent of the fog-related problems encountered by flight operations.[7] The best-known dissipation technique is heating because a small temperature increase is usually sufficient to evaporate the fog. Since heating usually isn't practical, the next most effective technique is hygroscopic seeding.[8] Hygroscopic seeding uses agents that absorb water vapor. This technique is most effective when accomplished from the air but can also be accomplished from the ground.[9] Optimal results require advance information on fog depth, liquid water content, and wind.[10]

Decades of research show that fog dissipation is an effective application of weather-modification technology with demonstrated savings of huge proportions for both military and civil aviation.[11] Local municipalities have also shown an interest in applying these techniques to improve the safety of high-speed highways transiting areas of frequently occurring dense fog.[12]

There are some emerging technologies which may have important applications for fog dispersal. As discussed earlier, heating is the most effective dispersal method for the most commonly occurring type of fog. Unfortunately, it has proved impractical for most situations and would be difficult at best for contingency operations. However, the development of directed radiant energy technologies, such as microwaves and lasers, could provide new possibilities.

Lab experiments have shown microwaves to be effective for the heat dissipation of fog. However, results also indicate that the energy levels required exceed the US large power density exposure limit of 100 watt/m^2 and would be very expensive.[13] Field experiments with lasers have demonstrated the capability to dissipate warm fog at an airfield with zero visibility. Generating one watt/cm^2, which is approximately the US large power density exposure limit, the system raised visibility to one quarter of a mile in 20 seconds.[14] Laser systems described in the Space Operations portion of this ***2025*** study could certainly provide this capability as one of their many possible uses.

With regard to seeding techniques, improvements in the materials and delivery methods are not only plausible but likely. Smart materials based on nanotechnology

are currently being developed with gigaops computer capability at their core. They could adjust their size to optimal dimensions for a given fog seeding situation and even make adjustments throughout the process. They might also enhance their dispersal qualities by adjusting their buoyancy, by communicating with each other, and by steering themselves within the fog. They will be able to provide immediate and continuous effectiveness feedback by integrating with a larger sensor network and can also change their temperature and polarity to improve their seeding effects.[15] As mentioned above, UAVs could be used to deliver and distribute these smart materials.

Recent army research lab experiments have demonstrated the feasibility of generating fog. They used commercial equipment to generate thick fog in an area 100 meters long. Further study has shown fogs to be effective at blocking much of the UV/IR/visible spectrum, effectively masking emitters of such radiation from IR weapons.[16] This technology would enable a small military unit to avoid detection in the IR spectrum. Fog could be generated to quickly, conceal the movement of tanks or infantry, or it could conceal military operations, facilities, or equipment. Such systems may also be useful in inhibiting observations of sensitive rear-area operations by electro-optical reconnaissance platforms.[17]

Storms

The desirability to modify storms to support military objectives is the most aggressive and controversial type of weather modification. The damage caused by storms is indeed horrendous. For instance, a tropical storm has an energy equal to 10,000 one-megaton hydrogen bombs,[18] and in 1992 Hurricane Andrew totally destroyed Homestead AFB, Florida, caused the evacuation of most military aircraft in the southeastern US, and resulted in $15.5 billion of damage.[19] However, as one would expect based on a storm's energy level, current scientific literature indicates that there are definite physical limits on mankind's ability to modify storm systems. By taking this into account along with political, environmental, economic, legal, and moral considerations, we will confine our analysis of storms to localized thunderstorms and thus do not consider major storm systems such as hurricanes or intense low-pressure systems.

At any instant there are approximately 2,000 thunderstorms taking place. In fact 45,000 thunderstorms, which contain heavy rain, hail, microbursts, wind shear, and lightning form daily.[20] Anyone who has flown frequently on commercial aircraft has probably noticed the extremes that pilots will go to avoid thunderstorms. The danger of thunderstorms was clearly shown in August 1985 when a jumbo jet crashed killing 137 people after encountering microburst wind shears during a rain squall.[21] These forces of nature impact all aircraft and even the most advanced fighters of 1996 make every attempt to avoid a thunderstorm.

Will bad weather remain an aviation hazard in 2025? The answer, unfortunately, is "yes," but projected advances in technology over the next 30 years will diminish the hazard potential. Computer-controlled flight systems will be able to "autopilot" aircraft through rapidly changing winds. Aircraft will also have highly accurate, onboard sensing systems that can instantaneously "map" and automatically guide the aircraft through the safest portion of a storm cell. Aircraft are envisioned to have hardened electronics that can withstand the effects of lightning strikes and may also have the capability to generate a surrounding electropotential field that will neutralize or repel lightning strikes.

Assuming that the US achieves some or all of the above outlined aircraft technical advances and maintains the technological "weather edge" over its potential adversaries, we can next look at how we could modify

the battlespace weather to make the best use of our technical advantage.

Weather-modification technologies might involve techniques that would increase latent heat release in the atmosphere, provide additional water vapor for cloud cell development, and provide additional surface and lower atmospheric heating to increase atmospheric instability. Critical to the success of any attempt to trigger a storm cell is the preexisting atmospheric conditions locally and regionally. The atmosphere must already be conditionally unstable and the large-scale dynamics must be supportive of vertical cloud development. The focus of the weather-modification effort would be to provide additional "conditions" that would make the atmosphere unstable enough to generate cloud and eventually storm cell development. The path of storm cells once developed or enhanced is dependent not only on the mesoscale dynamics of the storm but the regional and synoptic (global) scale atmospheric wind flow patterns in the area which are currently not subject to human control.

As indicated, the technical hurdles for storm development in support of military operations are obviously greater than enhancing precipitation or dispersing fog as described earlier. One area of storm research that would significantly benefit military operations is lightning modification. Most research efforts are being conducted to develop techniques to lessen the occurrence or hazards associated with lightning. This is important research for military operations and resource protection, but some offensive military benefit could be obtained by doing research on increasing the potential and intensity of lightning. Concepts to explore include increasing the basic efficiency of the thunderstorm, stimulating the triggering mechanism that initiates the bolt, and triggering lightning such as that which struck Apollo 12 in 1968.[22] Possible mechanisms to investigate would be ways to modify the electropotential characteristics over certain targets to induce lightning strikes on the desired targets as the storm passes over their location.

In summary, the ability to modify battlespace weather through storm cell triggering or enhancement would allow us to exploit the technological "weather" advances of our 2025 aircraft; this area has tremendous potential and should be addressed by future research and concept development programs.

Exploitation of "Near Space" for Space Control

This section discusses opportunities for control and modification of the ionosphere and near-space environment for force enhancement; specifically to enhance our own communications, sensing, and navigation capabilities and/or impair those of our enemy. A brief technical description of the ionosphere and its importance in current communications systems is provided in appendix A.

By 2025, it may be possible to modify the ionosphere and near space, creating a variety of potential applications, as discussed below. However, before ionospheric modification becomes possible, a number of evolutionary advances in space weather forecasting and observation are needed. Many of these needs were described in a SPACECAST 2020 study, *Space Weather Support for Communications*.[23] Some of the suggestions from this study are included in appendix B; it is important to note that our ability to exploit near space via active modification is dependent on successfully achieving reliable observation and prediction capabilities.

Opportunities Afforded by Space Weather Modification

Modification of the near-space environment is crucial to battlespace dominance. Gen Charles Horner, former commander in chief, United States Space Command, described his worst nightmare as "seeing an entire Marine battalion wiped out on some

foreign landing zone because he was unable to deny the enemy intelligence and imagery generated from space."[24] Active modification could provide a "technological fix" to jam the enemy's active and passive surveillance and reconnaissance systems. In short, *an operational capability to modify the near-space environment would ensure space superiority in 2025; this capability would allow us to shape and control the battlespace via enhanced communication, sensing, navigation, and precision engagement systems.*

While we recognize that technological advances may negate the importance of certain electromagnetic frequencies for US aerospace forces in 2025—such as radio frequency (RF), high frequency (HF), and very high frequency (VHF) bands—the capabilities described below are nevertheless relevant. Our nonpeer adversaries will most likely still depend on such frequencies for communications, sensing, and navigation and would thus be extremely vulnerable to disruption via space weather modification.

Communications Dominance via Ionospheric Modification

Modification of the ionosphere to enhance or disrupt communications has recently become the subject of active research. According to Lewis M. Duncan and Robert L. Showen, the Former Soviet Union (FSU) conducted theoretical and experimental research in this area at a level considerably greater than comparable programs in the West.[25] There is a strong motivation for this research, because

> induced ionospheric modifications may influence, or even disrupt, the operation of radio systems relying on propagation through the modified region. The controlled generation or accelerated dissipation of ionospheric disturbances may be used to produce new propagation paths, otherwise unavailable, appropriate for selected RF missions.[26]

A number of methods have been explored or proposed to modify the ionosphere, including injection of chemical vapors and heating or charging via electromagnetic radiation or particle beams (such as ions, neutral particles, X rays, MeV particles, and energetic electrons).[27] It is important to note that many techniques to modify the upper atmosphere have been successfully demonstrated experimentally. Ground-based modification techniques employed by the FSU include vertical HF heating, oblique HF heating, microwave heating, and magnetospheric modification.[28] Significant military applications of such operations include low frequency (LF) communication production, HF ducted communications, and creation of an artificial ionosphere (discussed in detail below). Moreover, developing countries also recognize the benefit of ionospheric modification: "in the early 1980's, Brazil conducted an experiment to modify the ionosphere by chemical injection."[29]

Several high-payoff capabilities that could result from the modification of the ionosphere or near space are described briefly below. It should be emphasized that this list is not comprehensive; modification of the ionosphere is an area rich with potential applications and there are also likely spin-off applications that have yet to be envisioned.

Ionospheric mirrors for pinpoint communication or over-the-horizon (OTH) radar transmission. The properties and limitations of the ionosphere as a reflecting medium for high-frequency radiation are described in appendix A. The major disadvantage in depending on the ionosphere to reflect radio waves is its variability, which is due to normal space weather and events such as solar flares and geomagnetic storms. The ionosphere has been described as a crinkled sheet of wax paper whose relative position rises and sinks depending on weather conditions. The surface topography of the crinkled paper also constantly changes, leading to variability in its reflective, refractive, and transmissive properties.

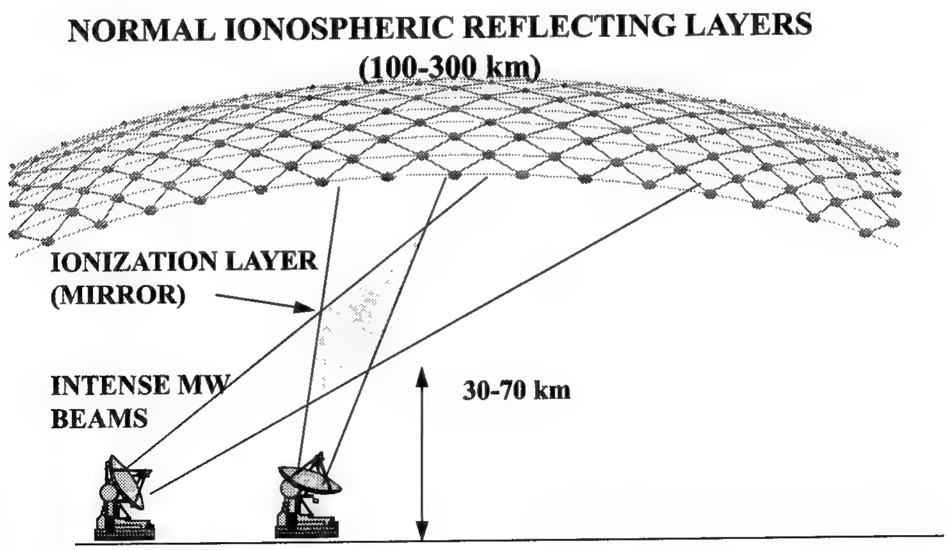
Creation of an artificial uniform ionosphere was first proposed by Soviet researcher A. V. Gurevich in the mid-1970s.

An artificial ionospheric mirror (AIM) would serve as a precise mirror for electromagnetic radiation of a selected frequency or a range of frequencies. It would thereby be useful for both pinpoint control of friendly communications and interception of enemy transmissions.

This concept has been described in detail by Paul A. Kossey and others in a paper entitled "Artificial Ionospheric Mirrors (AIM)."[30] The authors describe how one could precisely control the location and height of the region of artificially produced ionization using crossed microwave (MW) beams, which produce atmospheric breakdown (ionization) of neutral species. The implications of such control are enormous: one would no longer be subject to the vagaries of the natural ionosphere but would instead have direct control of the propagation environment. Ideally, the AIM could be rapidly created and then would be maintained only for a brief operational period. A schematic depicting the crossed-beam approach for generation of an AIM is shown in figure 4-1.[31]

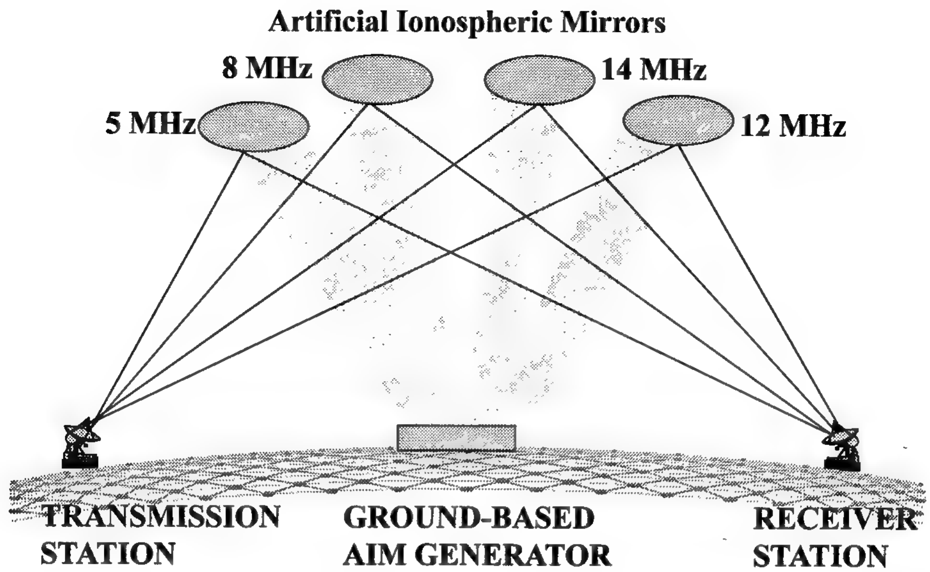
An AIM could theoretically reflect radio waves with frequencies up to 2 GHz, which is nearly two orders of magnitude higher than those waves reflected by the natural ionosphere. The MW radiator power requirements for such a system are roughly an order of magnitude greater than 1992 state-of-the-art systems; however, by 2025 such a power capability is expected to be easily achievable.

Besides providing pinpoint communication control and potential interception capability, this technology would also provide communication capability at specified frequencies, as desired. Figure 4-2 shows how a ground-based radiator might generate a series of AIMs, each of which would be tailored to reflect a selected transmission frequency. Such an arrangement would greatly expand the available bandwidth for communications and also eliminate the problem of interference and crosstalk (by allowing one to use the requisite power level).



Source: Microsoft Clipart Gallery © 1995 with courtesy from Microsoft.

Figure 4-1. The Crossed-Beam Approach for Generating an Artificial Ionospheric Mirror



Source: Microsoft Clipart Gallery © 1995 with courtesy from Microsoft.

Figure 4-2. Artificial Ionospheric Mirrors Can Provide Point-to-Point Communication Capability at Specified Frequencies as Desired

Kossey and others also describe how AIMs could be used to improve the capability of OTH radar:

> AIM based radar could be operated at a frequency chosen to optimize target detection, rather than be limited by prevailing ionospheric conditions. This, combined with the possibility of controlling the radar's wave polarization to mitigate clutter effects, could result in reliable detection of cruise missiles and other low observable targets.[32]

A schematic depicting this concept is shown in figure 4-3. Potential advantages over conventional OTH radars include frequency control, mitigation of auroral effects, short range operation, and detection of a smaller cross-section target.

Disruption of communications and radar via ionospheric control. A variation of the capability proposed above is ionospheric modification to disrupt an enemy's communication or radar transmissions. Because HF communications are controlled directly by the ionosphere's properties, an artificially created ionization region could conceivably disrupt an enemy's electromagnetic transmissions. Even in the absence of an artificial ionization patch, high-frequency modification produces large-scale ionospheric variations which alter HF propagation characteristics. The payoff of research aimed at understanding how to control these variations could be high as both HF communication enhancement and degradation are possible. Offensive interference of this kind would likely be indistinguishable from naturally occurring space weather. This capability could also be employed to precisely locate the source of enemy electromagnetic transmissions.

VHF, UHF, and superhigh frequency (SHF) satellite communications could be disrupted by creating artificial ionospheric scintillation. This phenomenon causes fluctuations in the phase and amplitude of radio waves over a very wide band (30 MHz to 30 GHz). HF modification produces electron density irregularities that cause scintillation over a wide-range of frequencies. The size of the irregularities determines which frequency band will be affected. Understanding how to control the spectrum

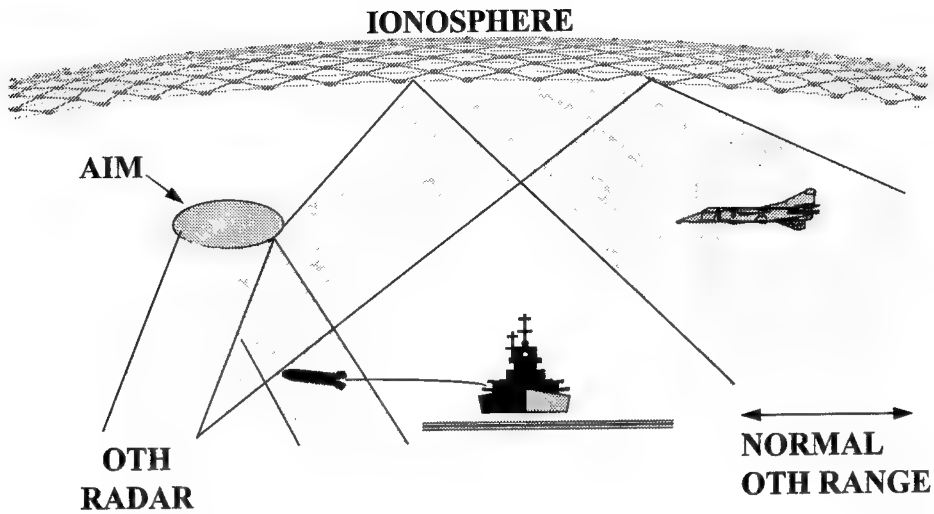


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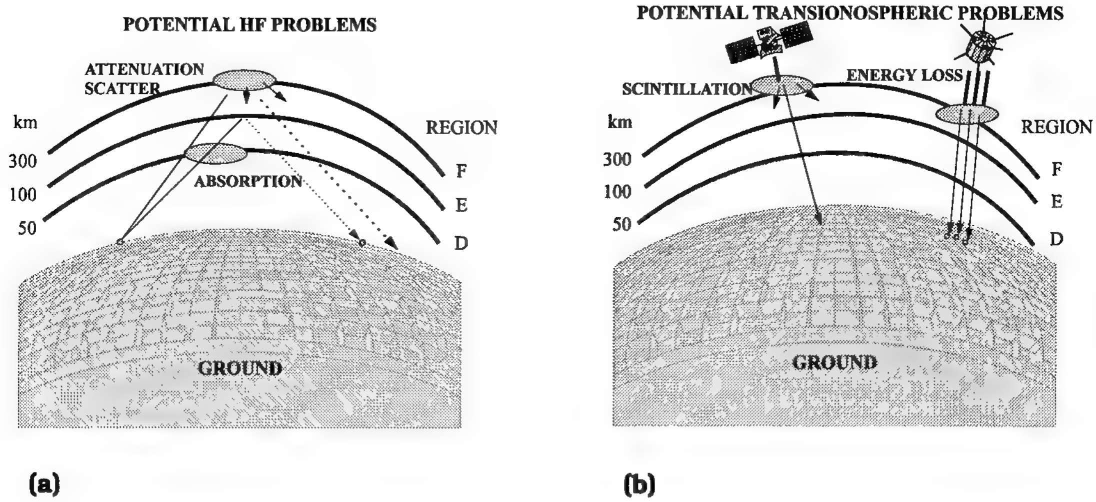
Figure 4-3. Artificial Ionospheric Mirror Over-the-Horizon Surveillance Concept

of the artificial irregularities generated in the HF modification process should be a primary goal of research in this area. Additionally, it may be possible to suppress the growth of natural irregularities resulting in reduced levels of natural scintillation. Creating artificial scintillation would allow us to disrupt satellite transmissions over selected regions. Like the HF disruption described above, such actions would likely be indistinguishable from naturally occurring environmental events. Figure 4-4 shows how artificially ionized regions might be used to disrupt HF communications via attenuation, scatter, or absorption (fig. 4-4a) or degrade satellite communications via scintillation or energy loss (fig. 4-4b) (from Ref. 25).

Exploding/disabling space assets traversing near space. The ionosphere could potentially be artificially charged or injected with radiation at a certain point so that it becomes inhospitable to satellites or other space structures. The result could range from temporarily disabling the target to its complete destruction via an induced explosion. Of course, effectively employing such a capability depends on the ability to apply it selectively to chosen regions in space.

Charging space assets by near-space energy transfer. In contrast to the injurious capability described above, regions of the ionosphere could potentially be modified or used as-is to revitalize space assets, for instance by charging their power systems. The natural charge of the ionosphere may serve to provide most or all of the energy input to the satellite. There have been a number of papers in the last decade on electrical charging of space vehicles; however, according to one author, "in spite of the significant effort made in the field both theoretically and experimentally, the vehicle charging problem is far from being completely understood."[33] While the technical challenge is considerable, the potential to harness electrostatic energy to fuel the satellite's power cells would have a high payoff, enabling service life extension of space assets at a relatively low cost. Additionally, exploiting the capability of powerful HF radio waves to accelerate electrons to relatively high energies may also facilitate the degradation of enemy space assets through directed bombardment with the HF-induced electron beams. As



Source: Microsoft Clipart Gallery © 1995 with courtesy from Microsoft.

Figure 4-4. Scenarios for Telecommunications Degradation Based on Ionospheric Modification (a) Attenuation, Scatter, and Absorption of HF Communications (b) Scintillation and Energy Loss of SHF Communications

with artificial HF communication disruptions and induced scintillation, the degradation of enemy spacecraft with such techniques would be effectively indistinguishable from natural environment effects. The investigation and optimization of HF acceleration mechanisms for both friendly and hostile purposes is an important area for future research efforts.

Artificial Weather

While most weather-modification efforts rely on the existence of certain preexisting conditions, it may be possible to produce some weather effects artificially, regardless of preexisting conditions. For instance, virtual weather could be created by influencing the weather information received by an end user. Their perception of parameter values or images from global or local meteorological information systems would differ from reality. This difference in perception would lead the end user to make degraded operational decisions.

Nanotechnology also offers possibilities for creating simulated weather. A cloud, or several clouds, of microscopic computer particles, all communicating with each other and with a larger control system could provide tremendous capability. Interconnected, atmospherically buoyant, and having navigation capability in three dimensions, such clouds could be designed to have a wide range of properties. They might exclusively block optical sensors or could adjust to become impermeable to other surveillance methods. They could also provide an atmospheric electrical potential difference, which otherwise might not exist, to achieve precisely aimed and timed lightning strikes. Even if power levels achieved were insufficient to be an effective strike weapon, the potential for psychological operations in many situations could be fantastic.

One major advantage of using simulated weather to achieve a desired effect is that unlike other approaches, it makes what are otherwise the results of deliberate actions appear to be the consequences of natural weather phenomena. In addition, it is potentially relatively inexpensive to do.

According to J. Storrs Hall, a scientist at Rutgers University conducting research on nanotechnology, production costs of these nanoparticles could be about the same price per pound as potatoes.[34] This of course discounts research and development costs, which will be primarily borne by the private sector and be considered a sunk cost by 2025 and probably earlier.

Concept of Operations Summary

Weather affects everything we do, and weather modification can enhance our ability to dominate the aerospace environment. It gives the commander tools to shape the battlespace. It gives the logistician tools to optimize the process. It gives the warriors in the cockpit an operating environment literally crafted to their needs. Some of the potential capabilities a weather-modification system could provide to a war-fighting CINC are summarized in table 1.

Notes

1. A pilot program known as Project Popeye conducted in 1966 attempted to extend the monsoon season in order to increase the amount of mud on the Ho Chi Minh trail thereby reducing enemy movements. A silver iodide nuclei agent was dispersed from WC-130, F4 and A-1E aircraft into the clouds over portions of the trail winding from North Vietnam through Laos and Cambodia into South Vietnam. Positive results during this initial program led to continued operations from 1967 to 1972. While the effects of this program remain disputed, some scientists believe it resulted in a significant reduction in the enemy's ability to bring supplies into South Vietnam along the trail. E. M. Frisby, "Weather Modification in Southeast Asia, 1966–1972," *The Journal of Weather Modification* 14, no. 1 (April 1982): 1–3.

2. William M. Gray et al., "Weather Modification by Carbon Dust Absorption of Solar Energy," *Journal of Applied Meteorology* 15 (April 1976): 355.

3. Ibid.

4. Ibid.

5. Ibid., 367.

6. AWS PLAN 813 Appendix I Annex Alfa (Scott AFB, Ill.: Air Weather Service/MAC, 14 January 1972), 11. Hereafter cited as Annex Alfa.

7. Capt Frank G. Coons, "Warm Fog Dispersal—A Different Story," *Aerospace Safety* 25, no. 10 (October 1969): 16.

8. Annex Alfa, 14.

9. Warren C. Kocmond, "Dissipation of Natural Fog in the Atmosphere," *Progress of NASA Research on Warm Fog Properties and Modification Concepts*, NASA SP-212 (Washington, D.C.: Scientific and Technical Information Division of the Office of Technology Utilization of the National Aeronautics and Space Administration, 1969), 74.

10. James E. Jiusto, "Some Principles of Fog Modification with Hygroscopic Nuclei," *Progress of NASA Research on Warm Fog Properties and Modification Concepts*, NASA SP-212 (Washington, D.C.: Scientific and Technical Information Division of the Office of Technology Utilization of the National Aeronautics and Space Administration, 1969), 37.

11. Maj Roy Dwyer, *Category III or Fog Dispersal*, M-U 35582-7 D993a c.1 (Maxwell AFB, Ala.: Air University Press, May 1972), 51.

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13. Milton M. Klein, *A Feasibility Study of the Use of Radiant Energy for Fog Dispersal*, Abstract (Hanscom AFB, Mass.: Air Force Material Command, October 1978).

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15. J. Storrs Hall, "Overview of Nanotechnology," adapted from papers by Ralph C. Merkle and K. Eric Drexler, Internet address: http://nanotech.rutgers.edu/nanotech-/intro.html, Rutgers University, November 1995.

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17. Christopher Centner et al., "Environmental Warfare: Implications for Policymakers and War Planners" (Maxwell AFB, Ala.: Air Command and Staff College, May 1995), 39.

18. Louis J. Battan, *Harvesting the Clouds* (Garden City, N.Y.: Doubleday & Co., 1960), 120.

19. Facts on File 55, no. 2866 (2 November 1995).

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21. Ibid., 140.

22. Heinz W. Kasemir, "Lightning Suppression by Chaff Seeding and Triggered Lightning," in Wilmot N. Hess, ed., *Weather and Climate Modification* (New York: John Wiley & Sons, 1974), 623–28.

23. SPACECAST 2020, *Space Weather Support for Communications*, white paper G (Maxwell AFB, Ala.: Air War College/2020, 1994).

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25. Lewis M. Duncan and Robert L. Showen, "Review of Soviet Ionospheric Modification Research," in *Ionospheric Modification and Its Potential to Enhance or Degrade the Performance of Military Systems,* (AGARD Conference Proceedings 485, October 1990), 2-1.

26. Ibid.

27. Peter M. Banks, "Overview of Ionospheric Modification from Space Platforms," in *Ionospheric Modification and Its Potential to Enhance or Degrade the Performance of Military Systems* (AGARD Conference Proceedings 485, October 1990), 19-1.

28. Capt Mike Johnson, *Upper Atmospheric Research and Modification—Former Soviet Union* (U), DST-18205-475-92 (Foreign Aerospace Science and Technology Center, AF Intelligence Command, 24 September 1992), 3. (Secret) Information extracted is unclassified.

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30. Paul A. Kossey et al. "Artificial Ionospheric Mirrors (AIM)," in *Ionospheric Modification and Its Potential to Enhance or Degrade the Performance of Military Systems* (AGARD Conference Proceedings 485, October 1990), 17A-1.

31. Ibid., 17A-7.

32. Ibid., 17A-10.

33. B. N. Maehlum and J. Troim, "Vehicle Charging in Low Density Plasmas," in *Ionospheric Modification and Its Potential to Enhance or Degrade the Performance of Military Systems* (AGARD Conference Proceedings 485, October 1990), 24-1.

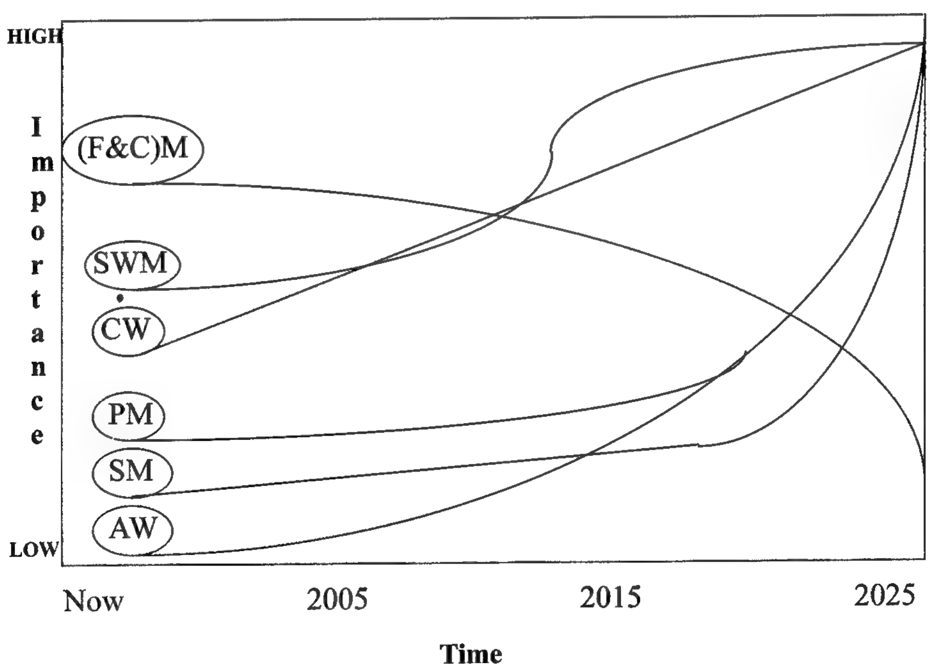
34. Hall.

Chapter 5

Investigation Recommendations: How Do We Get There from Here?

To fully appreciate the development of the specific operational capabilities weather modification could deliver to the war fighter, we must examine and understand their relationship to associated core competencies and the development of their requisite technologies. Figure 5-1 combines the specific operational capabilities of table 1 into six core capabilities and depicts their relative importance over time. For example, fog and cloud modification are currently important and will remain so for some time to come to conceal our assets from surveillance or improve landing visibility at airfields. However, as surveillance assets become less optically dependent and aircraft achieve a truly global all-weather landing capability, fog and cloud modification applications become less important.

In contrast, artificial weather technologies do not currently exist. But as they are developed, the importance of their potential applications rises rapidly. For example, the anticipated proliferation of surveillance technologies in the future will make the ability to deny surveillance increasingly valuable. In such an environment, clouds made of smart particles such as described in chapter 4 could provide a premium capability.



PM	Precipitation Modification	**(F&C)M**	Fog and Cloud Modification
SM	Storm Modification	**CW**	Counter Weather
SWM	Space Weather Modification	**AW**	Artificial Weather

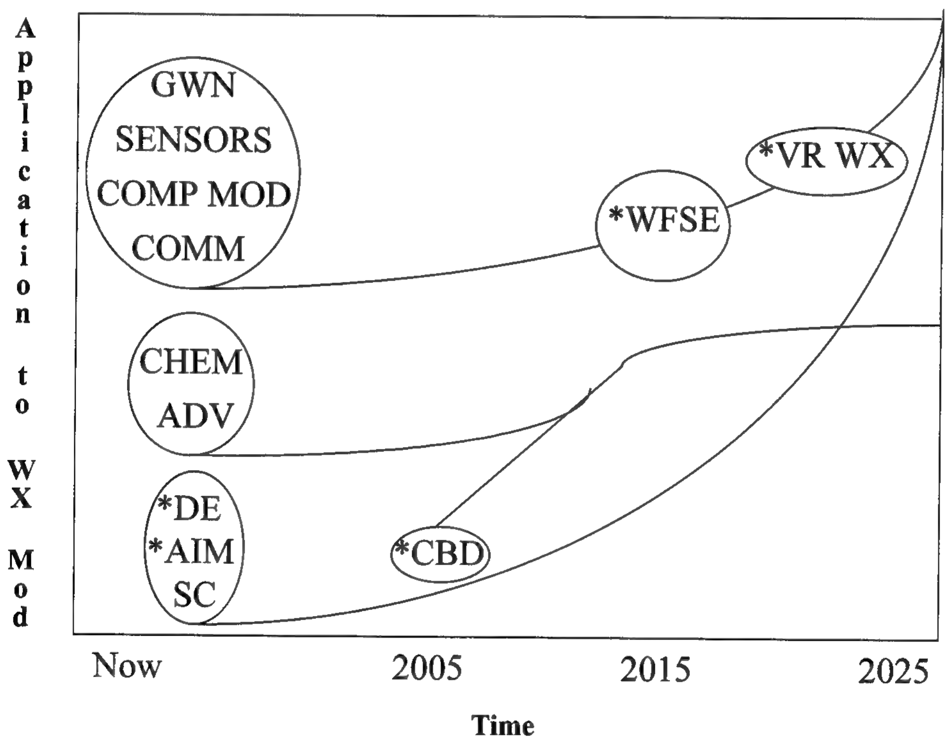
Figure 5-1. A Core Competency Road Map to Weather Modification in 2025

Even today's most technologically advanced militaries would usually prefer to fight in clear weather and blue skies. But as war-fighting technologies proliferate, the side with the technological advantage will prefer to fight in weather that gives them an edge. The US Army has already alluded to this approach in their concept of "owning the weather."[1] Accordingly, storm modification will become more valuable over time. The importance of precipitation modification is also likely to increase as usable water sources become more scarce in volatile parts of the world.

As more countries pursue, develop, and exploit increasing types and degrees of weather-modification technologies, we must be able to detect their efforts and counter their activities when necessary. As depicted, the technologies and capabilities associated with such a counter weather role will become increasingly important.

The importance of space weather modification will grow with time. Its rise will be more rapid at first as the technologies it can best support or negate proliferate at their fastest rates. Later, as those technologies mature or become obsolete, the importance of space weather modification will continue to rise but not as rapidly.

To achieve the core capabilities depicted in figure 5-1, the necessary technologies



ADV	Aerospace Delivery Vehicles	**DE**	Directed Energy
AIM	Artificial Ionospheric Mirrors	**GWN**	Global Weather Network
CHEM	Chemicals	**SC**	Smart Clouds (nanotechnology)
CBD	Carbon Black Dust	**SENSORS**	Sensors
COMM	Communications	**VR WX**	Virtual Weather
COMP MOD	Computer Modeling	*Technologies to be developed by DOD	
WFSE	Weather Force Support Element		

Figure 5-2. A Systems Development Road Map to Weather Modification in 2025

and systems might be developed according to the process depicted in figure 5-2. This figure illustrates the systems development timing and sequence necessary to realize a weather-modification capability for the battlespace by 2025. The horizontal axis represents time. The vertical axis indicates the degree to which a given technology will be applied toward weather modification. As the primary users, the military will be the main developer for the technologies designated with an asterisk. The civil sector will be the main source for the remaining technologies.

Conclusions

The world's finite resources and continued needs will drive the desire to protect people and property and more efficiently use our crop lands, forests, and range lands. The ability to modify the weather may be desirable both for economic and defense reasons. The global weather system has been described as a series of spheres or bubbles. Pushing down on one causes another to pop up.[2] We need to know when another power "pushes" on a sphere in their region, and how that will affect either our own territory or areas of economic and political interest to the US.

Efforts are already under way to create more comprehensive weather models primarily to improve forecasts, but researchers are also trying to influence the results of these models by adding small amounts of energy at just the right time and space. These programs are extremely limited at the moment and are not yet validated, but there is great potential to improve them in the next 30 years.[3]

The lessons of history indicate a real weather-modification capability will eventually exist despite the risk. The drive exists. People have always wanted to control the weather and their desire will compel them to collectively and continuously pursue their goal. The motivation exists. The potential benefits and power are extremely lucrative and alluring for those who have the resources to develop it. This combination of drive, motivation, and resources will eventually produce the technology. History also teaches that we cannot afford to be without a weather-modification capability once the technology is developed and used by others. Even if we have no intention of using it, others will. To call upon the atomic weapon analogy again, we need to be able to deter or counter their capability with our own. Therefore, the weather and intelligence communities must keep abreast of the actions of others.

As the preceding chapters have shown, weather modification is a force multiplier with tremendous power that could be exploited across the full spectrum of war-fighting environments. From enhancing friendly operations or disrupting those of the enemy via small-scale tailoring of natural weather patterns to complete dominance of global communications and counter-space control, weather modification offers the war fighter a wide range of possible options to defeat or coerce an adversary. But, while offensive weather-modification efforts would certainly be undertaken by US forces with great caution and trepidation, it is clear that we cannot afford to allow an adversary to obtain an exclusive weather-modification capability.

Notes

1. Mary Ann Seagraves and Richard Szymber, "Weather a Force Multiplier," *Military Review*, November/December 1995, 69.

2. Daniel S. Halacy, *The Weather Changers* (New York: Harper & Row, 1968), 202.

3. William Brown, "Mathematicians Learn How to Tame Chaos," *New Scientist*, 30 May 1992, 16.

Appendix A

Why Is the Ionosphere Important?

The ionosphere is the part of the earth's atmosphere beginning at an altitude of about 30 miles and extending outward 1,200 miles or more. This region consists of layers of free electrically charged particles that transmit, refract, and reflect radio waves, allowing those waves to be transmitted great distances around the earth. The interaction of the ionosphere on impinging electromagnetic radiation depends on the properties of the ionospheric layer, the geometry of transmission, and the frequency of the radiation. For any given signal path through the atmosphere, a range of workable frequency bands exists. This range, between the maximum usable frequency (MUF) and the lowest usable frequency (LUF), is where radio waves are reflected and refracted by the ionosphere much as a partial mirror may reflect or refract visible light.[1] The reflective and refractive properties of the ionosphere provide a means to transmit radio signals beyond direct "line-of-sight" transmission between a transmitter and receiver. Ionospheric reflection and refraction has therefore been used almost exclusively for long-range HF (from 3 to 30 MHz) communications. Radio waves with frequencies ranging from above 30 MHz to 300 GHz are usually used for communications requiring line-of-sight transmissions, such as satellite communications. At these higher frequencies, radio waves propagate through the ionosphere with only a small fraction of the wave scattering back in a pattern analogous to a sky wave. Communicators receive significant benefit from using these frequencies since they provide considerably greater bandwidths and thus have greater data-carrying capacity; they are also less prone to natural interference (noise).

Although the ionosphere acts as a natural "mirror" for HF radio waves, it is in a constant state of flux, and thus, its "mirror property" can be limited at times. Like terrestrial weather, ionospheric properties change from year to year, from day to day, and even from hour to hour. This ionospheric variability, called space weather, can cause unreliability in ground- and space-based communications that depend on ionospheric reflection or transmission. Space weather variability affects how the ionosphere attenuates, absorbs, reflects, refracts, and changes the propagation, phase, and amplitude characteristics of radio waves. These weather dependent changes may arise from certain space weather conditions such as: (1) variability of solar radiation entering the upper atmosphere; (2) the solar plasma entering the earth's magnetic field; (3) the gravitational atmospheric tides produced by the sun and moon; and (4) the vertical swelling of the atmosphere due to daytime heating of the sun.[2] Space weather is also significantly affected by solar flare activity, the tilt of the earth's geomagnetic field, and abrupt ionospheric changes resulting from events such as geomagnetic storms.

In summary, the ionosphere's inherent reflectivity is a natural gift that humans have used to create long-range communications connecting distant points on the globe. However, natural variability in the ionosphere reduces the reliability of our communication systems that depend on ionospheric reflection and refraction (primarily HF). For the most part, higher frequency communications such as UHF, SHF, and EHF bands are transmitted through the ionosphere without distortion.

However, these bands are also subject to degradation caused by ionospheric scintillation, a phenomenon induced by abrupt variations in electron density along the signal path, resulting in signal fade caused by rapid signal path variations and defocusing of the signal's amplitude and/or phase.

Understanding and predicting ionospheric variability and its influence on the transmission and reflection of electromagnetic radiation has been a much studied field of scientific inquiry. Improving our ability to observe, model, and forecast space weather will substantially improve our communication systems, both ground and space-based. Considerable work is being conducted, both within the DOD and the commercial sector, on improving observation, modeling, and forecasting of space weather. While considerable technical challenges remain, we assume for the purposes of this study that dramatic improvements will occur in these areas over the next several decades.

Notes

1. AU-18, *Space Handbook, An Analyst's Guide*, vol. 2 (Maxwell AFB, Ala.: Air University Press, December 1993), 196.

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Appendix B

Research to Better Understand and Predict Ionospheric Effects

According to a SPACECAST 2020 study titled, "Space Weather Support for Communications," the major factors limiting our ability to observe and accurately forecast space weather are (1) current ionospheric sensing capability; (2) density and frequency of ionospheric observations; (3) sophistication and accuracy of ionospheric models; and (4) current scientific understanding of the physics of ionosphere-thermosphere-magnetosphere coupling mechanisms.[1] The report recommends that improvements be realized in our ability to measure the ionosphere vertically and spatially; to this end an architecture for ionospheric mapping was proposed. Such a system would consist of ionospheric sounders and other sensing devices installed on DOD and commercial satellite constellations (taking advantage in particular of the proposed IRIDIUM system and replenishment of the GPS) and an expanded ground-based network of ionospheric vertical sounders in the US and other nations. Understanding and predicting ionospheric scintillation would also require launching of an equatorial remote sensing satellite in addition to the currently planned or deployed DOD and commercial constellations.

The payoff of such a system is an improvement in ionospheric forecasting accuracy from the current range of 40–60 percent to an anticipated 80–100 percent accuracy. Daily worldwide ionospheric mapping would provide the data required to accurately forecast diurnal, worldwide terrestrial propagation characteristics of electromagnetic energy from 3–300 MHz. This improved forecasting would assist satellite operators and users, resulting in enhanced operational efficiency of space systems. It would also provide an order of magnitude improvement in locating the sources of tactical radio communications, allowing for location and tracking of enemy and friendly platforms.[2] Improved capability to forecast ionospheric scintillation would provide a means to improve communications reliability by the use of alternate ray paths or relay to undisturbed regions. It would also enable operational users to ascertain whether outages were due to naturally occurring ionospheric variability as opposed to enemy action or hardware problems.

These advances in ionospheric observation, modeling, and prediction would enhance the reliability and robustness of our military communications network. In addition to their significant benefits for our existing communications network, such advances are also requisite to further exploitation of the ionsphere via active modification.

Notes

1. SPACECAST 2020, *Space Weather Support for Communications*, white paper G (Maxwell AFB, Ala.: Air War College/2020, 1994).

2. Referenced in ibid.

Appendix C

Acronyms

AOC	air operations center
AOR	area of responsibility
ATO	air tasking order
EHF	extra high frequency
GWN	global weather network
HF	high frequency
IR	infrared
LF	low frequency
LUF	lowest usable frequency
Mesoscale	less than 200 km^2
Microscale	immediate local area
MUF	maximum usable frequency
MW	microwave
OTH	over-the-horizon
PGM	precision-guided munitions
RF	radio frequency
SAR	synthetic aperture radar
SARSAT	search and rescue satellite-aided tracking
SHF	superhigh frequency
SPOT	satellite positioning and tracking
UAV	uninhabited aerospace vehicle
UV	ultraviolet
VHF	very high frequency
WFS	weather force specialist
WFSE	weather force support element
WX	weather

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Planetary Defense: Catastrophic Health Insurance for Planet Earth

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Executive Summary

Concern exists among an increasing number of scientists throughout the world regarding the possibility of a catastrophic event caused by an impact of a large earth-crossing object (ECO) on the Earth-Moon System (EMS), be it an asteroid or a comet. Such events, although rare for large objects (greater than 1 kilometer diameter), are not unprecedented. Indeed, the great upheaval and resulting ice age that marked the extinction of the dinosaurs is thought to have been caused by the impact of a 10 km diameter asteroid. In 1908 a stony asteroid of approximately 50 meters diameter exploded in the air above the Tunguska River in Siberia, producing an equivalent yield of 15–30 megatons of TNT, and leveling over 2,000 square miles of dense forest. Such an event is thought to occur approximately every century. It is only a matter of time before the world finds itself in a crisis situation—a crisis involving the detection of a large ECO, leaving little time to react and resulting in global panic, chaos, and possible catastrophe.

Collectively as a global community, no current viable capability exists to defend the EMS against a large ECO, leaving its inhabitants vulnerable to possible death and destruction of untold proportion and even possible extinction of the human race. In this regard, a planetary defense system (PDS) capability should be resourced, developed, and deployed. At this time Planetary Defense is not an assigned or approved mission of the Department of Defense or the Air Force. Such a system would consist of a detection subsystem, command, control, communications, computer, and intelligence (C^4I) subsystem and a mitigation subsystem. There are many potential variations of these subsystems which, with advances in novel technologies, will be available by 2025 to develop a credible PDS. We propose a three-tier system developed sequentially in time and space. Such a system would serve not only as a means to preserve life on earth but also help to unite the global community in a common effort that would promote peaceful cooperation and economic prosperity as related spin-offs and dual uses of novel technologies evolve.

Chapter 1

Introduction

If some day in the future we discover well in advance that an asteroid that is big enough to cause a mass extinction is going to hit the Earth, and then we alter the course of that asteroid so that it does not hit us, it will be one of the most important accomplishments in all of human history.

—Sen George E. Brown, Jr.

The Earth-Moon System (EMS) and its inhabitants are in danger. It is not the kind of danger that most people are familiar with such as disease, pestilence, or the threat of nuclear war, but one that is rapidly moving to the forefront of scientific research, exploration, and analysis—the very real hazard of a large earth-crossing object (ECO) impacting on the EMS. As the Earth revolves around the Sun, it periodically passes close to orbiting asteroids and comets, producing near-earth-object (NEO) situations. When asteroid or comet orbits intersect the orbit of the earth, they are referred to as ECOs. Clearly, a global effort is needed to deal with this problem and to provide perhaps the only means of preserving the human race from possible extinction.

Building on the 1993 *SPACECAST 2020* Study, this paper describes new research and analysis on the magnitude of the threat and possible mitigation systems.[1] It then proposes a mission statement and outlines the basic capability required in a functional planetary defense system (PDS). This "system of systems" is described in detail, working through the detection, analysis, and mitigation subsystems that comprise the PDS. Included in this development are novel concepts using new technologies and capabilities expected to be available in the years prior to 2025, facilitating a variety of courses of action, and moving the community away from the less-than-desirable nuclear solution. It also provides, an overall concept of operations which describes how these subsystems work together to provide the needed capability against threat objects from space. A three-tier system is proposed. Several commercial applications and benefits are considered as spin-offs or as dual-use capabilities of the PDS. Finally, specific recommendations are provided which are keyed toward generating increased interest, emphasis, funding, research, development, and deployment of a PDS to deal with this rare but potentially catastrophic problem.

The Threat

The earth lies at the center of a cosmic shooting gallery consisting of asteroids and comets, racing through space at velocities relative to the earth of up to 75 times the speed of sound.[2] These extraterrestrial objects are material left over from the formation of the solar system; basically, they are material that never coalesced into planets. Asteroids are rocky and metallic objects that orbit the Sun, ranging in diameter from mere pebbles to about 1,000 kilometers. They are generally found in a main orbital belt between Mars and Jupiter. Comets, on the other hand, contain ice, clay, and organic matter and are commonly referred to as "dirty snowballs" because of their opaque appearance. Like asteroids, comets orbit the sun, typically in highly elliptical or even parabolic orbits.

Although ECO impacts involving large asteroids or comets are rare, they do occur. When they do, they have the potential for causing catastrophic destruction and loss of life. It is currently estimated that more than 2,000 ECOs in excess of 0.5 km in diameter do exist. Given the inadequate deep space detection capability, only a small percentage of these objects have been classified. Disturbingly, a sizable number of these potential threat objects are quite large. Ceres, for example, is 974 km in diameter and is currently the largest of the classified asteroids. Approximately 20 other asteroids fall into this mega-threat category. With the natural gravitational perturbations created by the planets, it is inevitable that one or more of these objects will someday impact the EMS.

Geologic history is replete with examples of actual ECO impacts. Indeed, many scientists argue that it was the impact of a huge asteroid, perhaps as large as 10 km in diameter, that created a global dust cloud and ultimately triggered climactic changes that caused the extinction of dinosaurs and up to 75 percent of other species then on earth. This event, called the Cretaceous/Tertiary (K/T) Impact, is believed to have produced an equivalent yield of 10^8 megatons of TNT.[3] Ancient writings and drawings contain numerous accounts of objects falling from the sky, causing death and destruction. A size and impact versus frequency graph is included as figure 1-1.

During the twentieth century, several impacts and near misses have been recorded. In 1908 a stony asteroid of approximately 50 meters in diameter exploded in the air above the Tunguska River in Siberia, producing an equivalent TNT yield of 15–30 megatons (MT) and leveling over 2,000 square miles of dense forest. Needless to say, had the Tunguska event occurred over a populated city, the results would have been catastrophic. In 1937 and again in 1989, large asteroids passed uncomfortably close to the earth. The 1989 asteroid would have unleashed the equivalent of more than 40,000 megaton of TNT had it impacted. More recently, in 1994, astronomers cautiously watched as a small asteroid missed the earth by only 60,000 miles. In 1996 comet Hyakutake passed within 9 million miles of earth (0.1 astronomical units [AU]), the nearest comet approach in six centuries, yet this body was discovered only three months prior to its closest approach to earth.[4]

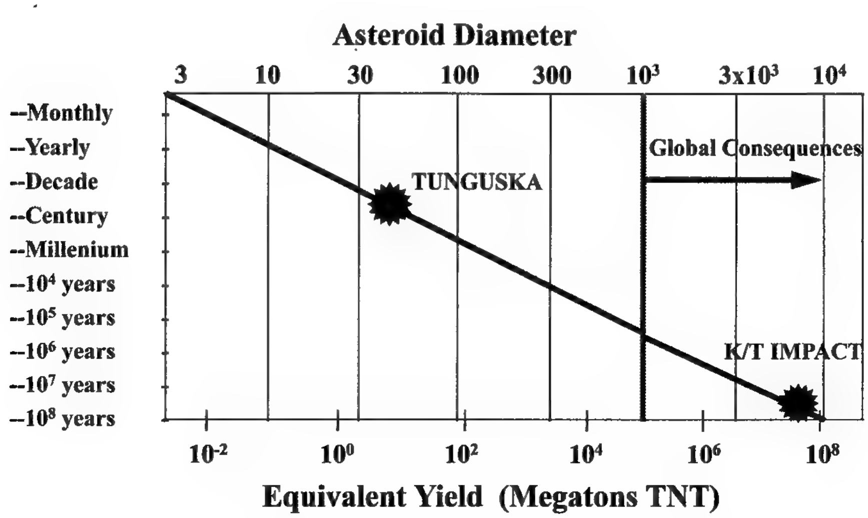

Figure 1-1. Asteroid Size/Impact versus Frequency

The earth continues to be struck by objects from space at irregular intervals, most of which are small pebble-sized rocks weighing only a few milligrams. Scientists estimate that a large number of meteoroids (asteroids that impact earth) enter the earth's atmosphere daily, amounting to several hundred tons of material each year.[5] Based on recent analysis, coupled with the exploration of over 120 impact craters on earth, researchers now believe that collisions involving large objects occur within centuries and millennia versus millions and billions of years, as originally estimated.[6] Additionally, data now indicates that multiple impacts are more common than previously thought. Although these frequencies of occurrence may seem to be inconsequential, requiring virtually no action or concern, the catastrophic effects associated with only one of these events demand that the global community unite to develop a defensive capability.

Vulnerability

Due to a lack of awareness and emphasis, the world is not socially, economically, or politically prepared to deal with the vulnerability of the EMS-to-ECO impacts and their potential consequences. Further, in terms of existing capabilities, there is currently a lack of adequate means of detection, command, control, communications, computers, and intelligence (C^4I), and mitigation.

Few people are even aware of an ECO problem, much less the potential consequences associated with its impact on the EMS. However, there are hopeful signs in correcting this deficiency as more frequent Planetary Defense workshops are being conducted with active participation by an increasing number of major countries. Nevertheless, other than a congressional mandate requiring further study of the problem, no further globally sanctioned action has been taken.

In terms of courses of action in the event of a likely impact of an ECO, other than a nuclear option, no defensive capability exists today. However, new technologies may yield safer and more cost-effective solutions by 2025. These authors contend that the stakes are simply too high not to pursue direct and viable solutions to the ECO problem. Indeed, the survival of humanity is at stake.

Notes

1. Much information was gathered from reports from recent conferences and workshops conducted to increase awareness and incite action in developing a cooperative solution within the global community, including: *The Spaceguard Survey: Report of the NASA International Near-Earth-Object Detection Workshop*, ed. David Morrison (Pasadena, Calif.: Jet Propulsion Laboratory, 1992); *Proceedings of the Near-Earth-Object Interception Workshop*, eds. G. H. Canavan, J. C. Solem, and J. D. G. Rather (Los Alamos, N.Mex.: Los Alamos National Laboratory, 1992); *Problems of Earth Protection Against the Impact with Near-Earth-Objects* (Livermore, Calif.: Lawrence Livermore National Laboratory, 1994).

2. Peter Tyson, "Comet Busters," *Planetary Defense Workshop: An International Technical Meeting on Active Defense of the Terrestrial Biosphere from Impacts by Large Asteroids and Comets* (Livermore, Calif.: Lawrence Livermore National Laboratory, 22–26 May 1995).

3. Tom Gehrels, "Collisions with Comets and Asteroids," *Scientific American* (March 1996), 57.

4. "C/1996 B2 (Hyakutake)," n.p.,: on-line, Internet, 30 May 1996, available from http://medicine.wustl.edu/%7Ekronkg/1996_B2.html.

5. Bob Kobres, "Meteor Defense," *Whole Earth Review* (Fall 1987): 70–73.

6. Victor Clube and Bill Napier, *Cosmic Winter* (Basil Blackwell, June 1993), 1–15.

Chapter 2

Social, Economic, and Political Implications

Nearly every century, the earth is impacted by an asteroid large enough to cause tens of thousands of deaths if they were to hit densely populated areas. On millennial time scales, impacts large enough to cause destruction comparable to the greatest known natural disasters may occur.[1]

Social Implications

Most of the world's population does not know or care about the prospect of cosmic collisions, although this hazard from space is a subject of deadly concern to humanity. Unfortunately, there are fewer than a dozen people currently searching for ECOs worldwide, fewer people than "it takes to run a single McDonalds."[2]

Many experts wrongly believe there have been no recorded deaths due to asteroid strikes, acknowledging only that there have been some close calls from small meteorites striking cars and houses.[3] However, planetologist John S. Lewis asserts in recent research that meteorites have in fact caused thousands of deaths throughout recorded history. Lewis details 123 cases of deaths, injuries, and property damage caused by ECO impacts reported over approximately a two-hundred-year period alone. Table 1 reflects known cases which caused injury or death.[4]

More recently, on 8 December 1992, a large asteroid named Toutatis missed earth by only two lunar distances. This was a fortunate day for everyone on earth, because this asteroid was nearly 4 kilometers in diameter.[5] If Toutatis had impacted earth, the force of the collision would have generated more energy than all the nuclear weapons in existence combined—equal to approximately 9×10^6 megatons of TNT.[6]

Finally, if you were standing on Kosrae Island, off the New Guinea coast on 1 February 1994, you would have witnessed a blast in the sky as bright as the sun. A small meteor traveling at approximately 33,500 miles per hour had entered the earth's atmosphere. Fortunately, the meteor exploded at high altitude, over a sparsely populated region; the blast equaling 11 kilotons (KT) of TNT.[7]

Regardless of the tendency to downplay the ECO threat, the probability of an eventual impact is finite. When it happens, the resulting disaster is expected to be devastatingly catastrophic. Scientists estimate the impact by an asteroid even as small as 0.5 kilometers could cause climate shifts sufficient to drastically reduce crop yields for one or several years due to atmospheric debris restricting sunlight. Impacts by objects one to two kilometers in size could therefore result in significant loss of life due to mass starvation. Few countries store as much as even one year's supply of food. The death toll from direct impact effects (blast and firestorm, as well as the climatic changes) could reach 25 percent of the world's population.[8] Although it may be a rare event, occurring only every few hundred thousand years, the average yearly fatalities from such an event could still exceed many natural disasters more common to the global population.

Because the risk is small for such an impact happening in the near future, the nature of the ECO impact hazard is beyond our experience. With the exception of the asteroid strike in Shansi, China, which reportedly killed more than 10,000 people in 1490, ECO impacts killing more than 100 people have not been reported within all of human history.[9] Natural disasters, including earthquakes, tornadoes, cyclones,

Table 1

Injuries and Deaths Caused by ECO Impacts

1420 BC	Israel - Fatal meteorite impact.
588 AD	China - 10 deaths; siege towers destroyed.
1321–68	China - People & animals killed; homes ruined.
1369	Ho-t'ao China - Soldier injured; fire.
02/03/1490	Shansi, China - 10,000 deaths.
09/14/1511	Cremona, Italy - Monk, birds, & sheep killed.
1633–64	Milono, Italy - Monk killed.
1639	China - Tens of deaths; 10 homes destroyed.
1647–54	Indian Ocean - 2 sailors killed aboard a ship.
07/24/1790	France - Farmer killed; home destroyed; cattle killed.
01/16/1825	Oriang, India - Man killed; woman injured.
02/27/1827	Mhow, India - Man injured.
12/11/1836	Macao, Brazil - Oxen killed; homes damaged.
07/14/1847	Braunau, Bohemia - Home struck by 371 lb meteorite.
01/23/1870	Nedagolla, India - Man stunned by meteorite.
06/30/1874	Ming Tung li, China - Cottage crushed, child killed.
01/14/1879	Newtown, Indiana, USA - Man killed in bed.
01/31/1879	Dun-Lepoelier, France - Farmer killed by meteorite.
11/19/1881	Grossliebenthal, Russia - Man injured.
03/11/1897	West Virginia, USA - Walls pierced, horse killed, man injured.
09/05/1907	Weng-li, China - Whole family crushed to death.
06/30/1908	Tunguska, Siberia - Fire, 2 people killed. (Referenced throughout paper)
04/28/1927	Aba, Japan - Girl injured by meteorite.
12/08/1929	Zvezvan, Yugoslavia - Meteorite hit bridal party, 1 killed.
05/16/1946	Santa Ana, Mexico - Houses destroyed, 28 injured.
11/30/1946	Colford, UK - Telephones knocked out, boy injured.
11/28/1954	Sylacauga, Alabama, USA - 4 kg meteorite struck home, lady injured.
08/14/1992	Mbole, Uganda - 48 stones fell, roofs damaged, boy injured.

tsunamis, volcanic eruptions, firestorms, and floods often kill thousands of people, and occasionally several million. In contrast to more familiar disasters, the postulated asteroid impact would result in massive devastation. For example, had the 1908 Tunguska event happened three hours later, Moscow would have been leveled. In another event occurring approximately 800 years ago on New Zealand's South Island, an ECO exploded in the sky, igniting fires and destroying thousands of acres of forests.[10] If such an event were to occur over an urban area, hundreds of thousands of people could be killed, and damage could be measured in hundreds of billions of dollars.[11]

A civilization-destroying impact overshadows all other disasters, since billions of people could be killed (as large a percentage loss of life worldwide as that experienced by Europe from the Black Death in the 14th century).[12] As the global population continues to increase, the probability of an ECO impact in a large urban center also increases proportionally.

Work over the last several years by the astronomical community supports that more impacts will inevitably occur in the future. Such impacts could result in widespread devastation or even catastrophic alteration of the global ecosystem.

During the last 15 years, research on ECOs has increased substantially. Fueled by the now widely accepted theory that a large asteroid impact caused the extinction of the dinosaurs, astronomy and geophysics

communities have focused more effort on this area. Astronomers, with more capable detection equipment, have been discovering potentially globally catastrophic 1 km and larger ECOs at an average rate of 25 each year.[13]

The combined results of these efforts help us to realize that there is a potentially devastating but still largely uncharacterized natural threat to earth's inhabitants. A disaster of this magnitude could put enormous pressure on the nations involved, destabilizing their economic and social fabrics. Certainly, such a disaster could affect the entire global community. Historically, governments have crumbled to lesser disasters because of a lack of resources and the inability to meet the needs of their people. Often only the infusion of external assistance has prevented more severe outcomes.

What will happen when a significant portion—such as one-quarter—of the world's population is in need of aid, especially when it is not known how long the effects may last? Thus, the time has come to investigate development of the necessary technologies and strategies for planetary defense. While living in day-to-day fear is not the answer, there is a sizable danger to our planet from an ECO impact. Numerous other species may now be extinct because they could not take preventive steps. We must avoid delusions of invincibility. Humans must acknowledge that, as a species, we may not have existed long enough to consciously experience such a catastrophic event. But we currently have the technological means for detecting and possibly mitigating the ECO threat. We would be remiss if we did not use it.

Economic Implications

The cost for a PDS system could be compared to buying a life insurance policy for the world. Applying our three-tier defensive plan could offer the best answer in convincing the world purseholders to invest in a long-term program. Gregory H. Canavan, senior scientific advisor for defense research at Los Alamos National Laboratory, and Johndale Solem, coordinator for advanced concepts at Los Alamos National Laboratory, suggested a possible graduated funding approach. A few million dollars each year could support necessary observation surveys and theoretical study on mitigation efforts. A few tens of millions each year could support research on interception technologies and procure the dedicated equipment needed to search for large earth-threatening ECOs. And a hundred million dollars could create a spacecraft, such as in the *Clementine I* and *II* projects to intercept ECOs for the necessary characterization and composition analyses of ECOs of all sizes.[14]

Cost

Millions of dollars each year are spent to warn people of hurricanes, earthquakes and floods.[15] Tens of millions of dollars to warn and mitigate a potential asteroid impact will be minor compared to what the costs will be in response to even a relatively small impact in a populated area. Responding to such an impact will require a concerted effort from many nations and will strain severely strain on the economic resources of the international community.[16]

In fact, recognizing the potential seriousness of such events, the Congress in 1990 mandated that the National Aeronautics and Space Administration (NASA) conduct two workshops to study the issue of NEOs. The first of these workshops, the International NEO Detection Workshop or "*Spaceguard Survey*," held in several sessions during 1991, defined a program for detecting kilometer-sized or larger NEOs. The second workshop, the NEO Interception Workshop, held in January 1992, studied issues in intercepting and deflecting or destroying those NEOs determined to be on a collision course. In related action, Congress also funded two asteroid intercept technology missions: *Clementine I* and *Clementine II*. *Clementine I* was launched in

1994 to demonstrate space-based interceptor "Brilliant Pebbles" technology. *Clementine II* is scheduled for launch in 1998. The United Nations has directed national labs, corporations, and universities to accomplish other studies.

Investment

Building a complicated PDS crash program at a cost of billions of dollars may not hold the answer. A proposed program of Air Force space surveillance and monitoring as well as such intercept tests as *Clementine II* will be considered.[17]

No known ECOs are projected to impact the earth today. However, our inadequate detection capability due to inadequate resourcing and technology limitations place humanity at significant risk. The bottom line is the finite probability that we eventually will have a significant ECO impact. Indeed, one day it will be exactly equal to one. A modest but prudent program is justified and may buy us all substantial peace of mind.

The *Spaceguard Survey* Workshop's proposed observation network consists of six dedicated astronomical telescopes widely dispersed worldwide with all sites data-linked to a central survey clearinghouse and coordination center. The proposal offers a good start, but the limited rate of detection it can support would mean that the comprehensive census of 1 kilometer and larger ECOs would take 20–25 years. Development and operational costs for this system are estimated at $50 million (a one-time cost) and $10–15 million (annually), respectively. It is reasonable to assume these costs will be shared by the minimum of five nations where observatories are located and other where other states are directly involved.[18]

Development of this system will benefit from the experience gained by numerous space surveillance missions from man-made Earth-orbiting satellites, which in turn will benefit from technology developed specifically for detection and tracking of asteroids. Once such a system is in full operation and completes the initial catalogue, it may detect most large ECOs years or even decades in advance, which will provide time to prevent a collision. Then, the primary attention of the system may be changed to the hundreds of thousands of smaller near-earth asteroids and comets which also will cause considerable concern, while maintaining a perpetual watch for elusive long-period comets of any threatening size.

However, the system may also alert us to the prospect that our doomsday is closer at hand than we currently realize. Since the 1994 comet Shoemaker-Levy 9 impact on Jupiter, many experts have recognized that collisions with objects larger than a few hundred meters in diameter not only can threaten humanity on a global scale but have a finite probability of occurring. This recent public exposure to the consequences of a major planetary impact should encourage some willingness to invest more money into detection and mitigation technologies.

We should also realize that the technology required for a system to mitigate the most likely of impact scenarios is, with a little concerted effort, within our grasp. There are no current means for preventing many such natural disasters as earthquakes, tornadoes, and typhoons. Some of these disasters can not even be detected in time to give adequate warning to the affected population. Such is not the case with ECOs. Humanity certainly has the technology that, with a relatively modest investment, to warn of an impending catastrophe, maybe years or decades in advance. In most cases, an associated mitigation system could use the latest nuclear explosives, space propulsion, guidance, and sensing and targeting technologies, coupled with spacecraft technology. These technologies already are related to defense capabilities, but how they are developed for use in space (and what effects they have) will offer invaluable experience for defense efforts.

We can maximize our investment by turning to the commercial world for technology development and highlight opportunities for dual-use possibilities.[19] Space operations will continue to grow at a rapid rate as a factor in United States military capabilities limited primarily by affordable access.

It is quite possible that the current assumption of "anything in space costs more than it would on the ground" may no longer hold true in 2025. With rapid progress being made in miniaturization and with a downward trend in spacelift costs, the option of placing detection system components in orbit rather than on earth may be a money saver. The orbiting components can be tasked around the clock without regard for the weather conditions on the surface.

Large savings in Department of Defense (DOD) spending could result by stopping military-only launch access to space and reducing investment in technologies the commercial world can develop.[20] Beyond deflecting or fragmenting a threatening ECO, there may be some great advantage in capturing an asteroid into earth orbit. In addition to the scientific lessons learned in such a mission, many benefits could be gained by mining the asteroid's natural resources. Large-scale mining operations, from a single asteroid, could net upwards to $25 trillion dollars in nickel, platinum, or cobalt metals to offset the cost of the mitigation system (table 2).[21]

Parking an asteroid in orbit slightly higher than geosynchronous might be an ideal base of operations to maintain and salvage geosynchronous communication and surveillance systems used in surveillance of the near-earth environment.

Orbits occupying Lagrange points, L4 and L5 (to be discussed later), offer the most cost-effective orbits due to minimum energy required to maintain orbit. A captured asteroid also could be used for large space-based manufacturing or even as a space dock for buildup of interplanetary missions, eliminating the expensive need to launch large systems out of the earth's gravity.[22]

Political Implications

Since planetary defense is a relatively new subject, there are no existing international treaties that specifically address it. However, in this section, we look at existing space treaties that offer relevance to planetary defense.[23] The Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, legally prohibiting weapons in space, provides perhaps the greatest restrictions to the concept of employing a Planetary Defense System (PDS).[24] Article 4 of this treaty, which became effective on 10 October 1967, states:

Table 2

Economic Analysis of 2 km Diameter M-Class Metal Rich Asteroid

Component	Fraction of Metal by Mass	Mass	Estimated Value $/(Kg)	Estimated Current Market Dollar Value (in trillion)
Iron	0.89	2.7×10^{13}	0.1	3
Nickel	0.10	3.0×10^{12}	3	9
Cobalt	0.005	1.5×10^{11}	25	4
Platinum-group metals	15ppm	4.5×10^{8}	20,000	9
Total Value				25

> Parties to the Treaty undertake not to place in orbit around the Earth any object carrying nuclear weapons or any other kinds of weapons of mass destruction, install such weapons on celestial bodies, or station such weapons in outer space in any other manner.[25]

Additionally, the Agreement Governing the Activities of States on the Moon and Other Celestial Bodies, enacted on 11 July 1979, applies to the Moon and other celestial bodies within the solar system.[26] Article 3 specifically restricts the use of nuclear weapons in space, stating:

> Parties shall not place in orbit or around the Moon objects carrying nuclear weapons or any other kinds of weapons of mass destruction or place or use such weapons on or in the Moon.[27]

Legal Aspects of Planetary Defense

Therefore, even though no existing treaties specifically prohibit the employment of a PDS, collectively, they provide enough legal restrictions to seriously affect the ability of operators to use it effectively when faced with a major extraterrestrial threat. In our extreme case involving the impending impact of an asteroid or comet and where the survival of the human race is potentially at risk, we assume that appropriate exceptions would be approved, allowing the use of nuclear weapons or other weapons of mass destruction to mitigate the threat. Indeed, these weapons could serve as the only means of saving the earth.

Fortunately, none of the existing treaties restrict the employment of detection devices—whether they be earth-, space-, or planet-based—that would serve as major components of the PDS. As discussed in the "Concept of Operations (CONOPS)" section, our three-tier PDS concept includes near-, mid-, and far-range detection systems. Obviously, early detection and classification of an asteroid or comet as an ECO allows more reaction time and permits greater flexibility in developing viable courses of action. Therefore, our PDS concept places significant emphasis on detection at the greatest possible range.

A decision to develop and ultimately deploy a planetary defense system will involve numerous developmental tests, both at the system and subsystem levels. Inevitably, however, politicians and engineers will be faced with the dilemma involving the need to test the system under realistic conditions using weapons in space. A limited number of these tests will involve nuclear weapons, predictably against a simulated or actual ECO. Such tests are currently banned by the Treaty Banning Nuclear Weapons Tests in the Atmosphere, in Outer Space, and Underwater, which became effective on 10 October 1963 and stated:

> Parties to undertake to prohibit, prevent and not to carry out any nuclear weapon test explosion, or any other nuclear explosion, at any place under its jurisdiction or control: (a) In the atmosphere, beyond its limits, including outer space, or under water, including territorial waters or high seas; or (b) In any other environment if such explosion causes radioactive debris to be present outside the territorial limits of the State under whose jurisdiction or control such explosion is conducted.[28]

One of the biggest objections against nuclear testing in space involves radioactive fallout reentering the atmosphere with deleterious effects. In the case involving a nuclear intercept of an actual ECO, the potential for death or injury due to fragmented asteroid impacts poses equal concern. The decision to use such weapons of mass destruction (WMD) would obviously involve much dialogue and debate, but, from an acquisition standpoint, such testing would be necessary to validate system credibility. With the united commitment of the global community, it is anticipated that the treaty restrictions mentioned earlier could be waived to permit such a test.

As the planetary defense problem becomes better understood and accepted within the global community, and as potential solutions, including a PDS, are developed, it will likely become necessary to selectively renegotiate existing treaties that currently prohibit testing and using weapons in space. Perhaps a treaty

specifically tailored to the evolutionary development of a planetary defense system as well as its use during an ECO threat crisis will be needed. Regardless of the outcome, however, it is safe to say that the use of weapons in space, especially WMD, will remain highly restricted.

European Perspective on Planetary Defense

If one nation, such as the US, attempted to place weapons in space, the world would likely oppose such an attempt. Therefore, the US would not likely attempt to forge a PDS alone. Realistically, the US would require a coalition with other nations, such as the Russians and Japanese, and other aerospace nations of the future, before placing weapons in space. While discussing the interaction of each of these nations is beyond the scope of this paper, the political and economic issues are worthy of comment since these factors will affect all participants. In this section, our Italian co-author, Ms Iole M. De Angelis, offers insight into this area, especially, from a European point of view.[29]

In analyzing the political structure and processes of the European continent, the first and most significant factor noted is that Europe is not a single political entity; hence policies reflect consensus among many different European countries. Similar to the democratic process in the United States, the European political organization allows for free-flowing discussion as issues are openly debated and agreements are ultimately reached. As is the case in the US, debate can be an extremely time-consuming process. In Europe, countries such as the United Kingdom (UK), have long enjoyed a close relationship and spirit of cooperation with the United States, while others, like France, have historically rejected US influence in European policy-making.

As discussed in this paper, the development, testing, and deployment costs of a planetary defense system likely will be staggering, especially if the three-tier PDS concept is adopted. However, we believe the catastrophic results of a large asteroid or comet impact, including the potential extinction of the human race, justify such an expenditure, especially if it can be incrementally funded. Obviously, since the planetary defense problem is global in nature, one should not expect that the PDS costs will be borne by one or even a few countries. Indeed, such an endeavor will certainly fail without the cooperation and commitment of the entire global community. In this sense, Europe must be a major player in the successful implementation of a PDS.

When considering future European involvement in space-related issues, it is important to include the activities of the European Space Agency (ESA), with its international perspective and influence. Without a doubt, the ESA will be critical to the successful development and deployment of the PDS, especially with its close ties to France as one of ESA's most influential members.

Since France does not favor the influence of the US on European policy decisions, the US should use caution as it identifies requirements and ideas for a PDS. However, considering the need for global funding to support the development of the technologies and capabilities required for such a system, the US also must maintain open lines of communication with every major player to achieve a viable solution to the planetary defense problem. Given the normal reluctance of most countries to accept solutions or direction originating from a superpower such as the US automatically, it may be more effective to use a neutral element as the lead to pull the global community together and develop a strategy that all parties can support. Further, since there will likely be reservations, mistrust, and possibly even rejection due to the dual-use potential of the PDS as a strategic weapon, a neutral element would help to alleviate such fears.

Because of its global charter, the United Nations is probably the best organization to assume the leadership role in pulling together the global community, educating it

about the planetary defense problem, garnering support for the development of a global PDS strategy, and ultimately serving as the primary advocate for the evolution of a functional planetary defense system to protect the EMS against ECO impacts. Clearly, the international influence of the UN will serve as an important foundation for the global community to implement the PDS strategic plan.

Both education and communication will be crucial to the success of the PDS developmental process. The ECO threat must be presented in layman's terms, not using complex scientific jargon, for the program to gain public support. For example, an 80-year-old grandmother must be able to understand why a part of her pension will be used to pay for this system. Public opinion will influence political decisions regarding funding and research and development commitments.

In any case, it is important to distinguish between education and information, because, while we need to make people aware of ECO problems, we do not want to create panic or anxiety. One way to promote awareness is through the use of thought-provoking television documentaries and movies such as *Meteor*.[30] The Internet offers another way to educate the public about planetary defense issues. However, since many people do not own a computer, it is not as effective as television yet for reaching the large numbers we will need to educate.

Communication problems commonly exist between politicians, scientists, engineers, and the general public, not because these groups lack the desire to work together, but because of their inherent language differences. Realizing that the scientific community alone will not bring the PDS program to fruition, these groups must resolve their communication problems as early as possible and ultimately speak with one voice, especially when it comes to justifying commitments of limited resources.

Since private enterprises and not governments produce systems, it will be important to achieve the cooperation of the global community to ensure that the economic needs of these enterprises are fulfilled. In this regard, it may be beneficial to adopt the ESA policy of *juste retour*, despite its inherent drawbacks in efficiency and economies of scale, to promote global commitment and cooperation.[31]

Considering the general willingness of governments to participate in large space projects and with the ever-present uncertainty of the budget process, it is conceivable that a consortium-based PDS effort could become another International Space Station (ISS). In the latter case, the ISS project ended up with many ideas, studies, and proposals, but offered little to nothing in the way of actual development due to normal budget fluctuations, infighting, and the resulting inability of the participants to absorb the exorbitant developmental costs. Like ISS, a repeat of this approach might also cause the PDS project to be added to the list of failures.

Planetary Defense as a European Space Policy Priority

In this section, we will take a look at planetary defense as a European space policy priority.[32] The ESA currently does not have an ECO detection program. A possible near-term solution might be the Infrared Space Observatory (ISO). The ISO is a long-duration observatory of celestial radiation sources. Using this system, astronomers will be able to observe low-temperature stars (stars hidden by dust that only infrared light can penetrate) and can even detect planetary systems similar to earth by searching for life forms outside the solar system.

Initially, ISO will analyze the planets of the solar system and their satellites. In particular, it will focus on *Titan*, because astronomers suspect that its atmosphere may host complex chemical processes similar to those supporting life on earth. ISO will eventually be added to the growing

number of observatories actively involved in detecting and classifying ECOs.[33]

Planetary defense is not a high priority in the minds of many Europeans today. This lack of concern is true especially at the political level, even with the projected ISO capabilities. Although ISO will serve as a valuable means of ECO detection, there is generally little awareness about the ECO impact threat within the European region. Yet, within Europe, there are significant scientific talents and resources that need to be integrated into the overall global effort. Hopefully, greater participation in planetary defense workshops will help to increase European awareness and, ultimately, stimulate interest in achieving a viable solution to the problem. Communications and education will be critical to obtaining European support and commitment and establishing planetary defense as a European space policy priority.

Alternate Futures and Political Outlook for Planetary Defense

We believe it is realistic to assume that the treaties governing operations and activities in space will change before 2025, because, like the treaties previously discussed, they depend on the international environment. They also depend on the evolution of technologies and changes in resource availability, as well as other needs, including for example, economic exploitation of NEOs for minerals and scarce resources.

The ***2025*** Project developed five alternate futures for the year 2025, plus one possible scenario for 2015, and based on that work, it is possible to imagine how treaties may evolve and whether the international environment will be favorable to the implementation of a planetary defense system.

In "Gulliver's Travails," the first future scenario, there is no place for a PDS, because each country is busy defending itself from the others, and there is no possibility for cooperation.[34] There is not enough money for space exploration or issues as the states are too busy with national and international problems. In fact, this scenario suggests that the existing treaties are sufficient.[35]

In the second scenario, "Zaibatsu,"[36] planetary cooperation is led by the UN to counter an asteroid threat to the earth in the year 2007.[37] In this scenario the international situation is favorable to cooperation, mostly in the economic field, and it is rational to think that the treaties on outer space will change to allow economic exploitation of space and allow for a PDS to evolve. As the world was able to survive an asteroid threat due to technological development, it is logical to assume that the world will be able, sometime during the 1997 to 2007 time frame, to deploy a PDS to mitigate the asteroid.

In the third scenario, "Digital Cacophony," it is difficult to envision a global PDS, because power is dispersed among many actors and governments.[38] However, it is rational to suppose that more than one actor or government has developed a PDS because of the ultrahigh-technology capabilities. Furthermore, in this scenario, national defense tactics are based upon a strong strategic defense. Therefore, it is reasonable to foresee technical capability to deal with and survive an ECO encounter.[39]

Planetary defense in the fourth scenario, "King Khan," strongly depends on the political will of the superpowers.[40] The technological capability is present, but the ECO threat is unimportant to the elites who are more worried about maintaining the international equilibrium. It is possible to presume the existence of some kind of WMD deployment in outer space.[41]

In the fifth scenario, "Halfs & Half-Naughts," there is a PDS system jointly developed by the US, China, Russia, and European Union.[42] However the reexplosion of war in the Balkans, earthquakes in California, wars in Africa, crisis in Cuba—all happening at the same time—make the coordination difficult among these countries.[43] But in case of a real and urgent menace, it is possible to ensure the survival

of the earth, thanks to the high level of technology.

In the 2015 scenario, "Crossroads," the world seems to favor cooperation after the success of several UN operations.[44] This international organization acquires new respect and new power that enables it to lead a cooperative effort to deploy a PDS and promote the exploitation of outer space.

In any case, these scenarios are just scenarios, and thus, they do not represent what will necessarily happen. They do provide options, however, and remind us that humanity still has time to choose a path of survival or a way of living and thinking about the environment, especially in regards to developing a PDS. The implementation of a PDS will offer nations a unique opportunity to cooperate in a legal fashion to provide for the survival of the EMS.

Planetary defense efforts need to be consolidated, coordinated, and expanded under international leadership. The US should not go it alone. The threat is global; detection efforts will require observation sites throughout the world, and other nations possess unique technologies, spacelift, and other space-related capabilities which also could be used to develop and deploy a PDS.

Any action should involve the international community. This thinking is particularly important as mitigation efforts could require nuclear capabilities, and these intentions could violate current arms control treaties. Furthermore, a handful of the thousands of nuclear weapons being deactivated under the Strategic Arms Reduction Talks (START) agreement might offer the most expeditious solution to this problem. START implications would require DOD involvement.

Why should the DOD take an active interest in the planetary defense issue? Given such a scenario, the effects could threaten the national security of the US, even if it were not physically impacted. Certainly, the international community cannot deal with a disaster in which a significant portion the world is destroyed. All surviving nations would be affected. The devastating blows to governmental and societal structures could be equivalent to those thought of when talking about a post-global-nuclear-war holocaust, but lacking perhaps the lethal radiation effects. More importantly, once a threat is detected in advance, the nation and perhaps the entire planet will quite naturally look to the DOD to provide the means, technical expertise, and leadership, in addition to the required forces, to counter such a threat to its citizens' lives and well-being. A number of other US organizations and agencies will certainly be involved, including NASA, Department of Energy (DOE), Federal Emergency Management Agency (FEMA), and Office of Foreign Disaster Assistance (OFDA) and national laboratories and universities.

There will also most likely be an international effort to include the United Nations. Currently, Russia, Great Britain, France, Canada, Japan, Australia, China, Italy, Czech Republic, and other nations have shown an interest in this topic. However, few organizations other than the DOD have the experience and capability to even attempt such an effort.

Russia, with its military and space infrastructure, is probably the only other nation capable of the task, but a consolidated effort will offer the best chance of survival. Suffice it to say that the DOD will form the core around which the others could organize.

The fact that it may only happen once in several lifetimes does not absolve the current defense team of at least a moral responsibility if it does happen, particularly if it had the means to prevent or at least mitigate it. Perhaps for the first time in not only human history but the entire history of the planet, the inhabitants of earth are on the verge of having such capability. Currently, the chemical and nuclear propulsion systems now in development offer the best options for planetary defense. Employment of nuclear devices in a standoff mode represents the gentle nudge of all the

options available. Though technically much more difficult, nuclear devices exploded on or beneath the object's surface impart 10 or more times the impulse of a standoff explosion.[45]

International concern for use of these weapons leads to many political questions and misgivings. Ironically, these devices "could be notably straightforward to create and safe to maintain because they derive from vast research and development expenditures and experience accumulated during the forty-five years of the Cold War."[46] Technically, without an appropriate reentry vehicle, these devices could not be used as ballistic weapons, though there is always the possibility of terrorism or misuse. In any event, effective international protocols and controls could be established through the United Nations to minimize downside potential.

The debate will certainly continue, however, as evidenced in *The Deflection Dilemma: Use vs. Misuse of Technologies for Avoiding Interplanetary Hazards,* "The potential for misuse of a system built in advance of an explicit need may in the long run expose us to a greater risk than the added protection it offers."[47] The greatest challenge involves the building of international coordination, cooperation, and support. The threat of ECOs is a global problem and one which the entire world community should be concerned with. Coordination between nations, international organizations, DOD, NASA, DOE, academia, and others in the scientific community is essential in establishing the building blocks for a credible PDS. It is necessary to build trust, coordinate resources, consolidate efforts, and seek cooperation with and support for similar efforts in the international community.

Notes

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3. "Meteorite House Call," *Sky & Telescope,* August 1993, 13.

4. John S. Lewis, *Rain of Iron and Ice* (Reading, Mass.: Addison-Wesley, 1996), 176–82.

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12. The NASA Ames Space Science Division, 2.4.

13. Lewis, 83.

14. Gregory H. Canavan, "The Cost and Benefit of Near-Earth Object Detection and Interception" in *Hazards Due to Comets and Asteroids,* ed. Tom Gehrels (Tucson, Ariz.: University of Arizona Press, 1994), 1157–88.

15. Chapman and Morrison, 39.

16. Canavan, 1157–88.

17. Ibid.

18. The NASA Ames Space Science Division, 8.1 and 9.3.

19. Ronald R. Fogleman and Sheila E. Widnall, memorandum to Dr McCall, *New World Vistas,* 15 December 1995, attach 1.

20. USAF Scientific Advisory Board, *New World Vistas: Air and Space Power for the 21st Century* (unpublished draft, the recommended actions executive summary volume, 15 December 1995), 63.

21. W. K. Hartmann and A. Sokolov, "Evaluating Space Resources," in *Hazards Due to Comets and Asteroids,* ed. Tom Gehrels (Tucson, Ariz.: University of Arizona Press, 1994), 1216.

22. Ibid.

23. This section was contributed by Ms Iole De Angelis, a graduate student at the International Space University, Strasbourg, France. Her participation in the ***2025*** *Project* came at the request of Air University to provide expertise in the areas of space treaties and international law. In addition, her insights lend an international flavor to a truly global problem.

24. "Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies," *Arms Control and Disarmament Agreements* (Washington D. C.: United States Arms Control and Disarmament Agency, 1982), 48–50.

25. Ibid., 52.

26. "Agreement Governing the Activities of States on the Moon and Other Celestial Bodies," 1979, n.p.; on-line, Internet, 30 May 1996, available from gopher://gopher.law.cornell.edu:70/00/foreign/fletcher.

27. "Treaty on Principles."

28. "Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water," 1963, n.p.; on-line, Internet, 30 May 1996, available from gopher://gopher.law.cornell.edu:70/00/foreign/fletcher.BH454.txt.

29. This section was contributed by Ms Iole De Angelis.

30. *Meteor*, dir. by Ronald Neame, prod. by Arnold Orgoline and Theodore Pareign (Hollywood: Orion Studios, 1979). The motion picture depicts a nuclear weapon system used to mitigate an ECO predicted to impact Earth.

31. The *juste retour* policy forces governmental and private interests to cooperate: from a given amount of money one government puts in the common project, private enterprises of its country receive comparable amounts to build the components. For example, there is a project that costs $100; country "A" finances for $50; country "B" for $30; and country "C" for $20. So the enterprises of country "A" will receive contracts for $50, the enterprises of country "B" will receive contracts for $30, and the enterprises of country "C" will receive contracts for $20.

32. This section was contributed by Ms Iole De Angelis.

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35. Ibid., 37.

36. Ibid., 55.

37. Ibid., 57.

38. Ibid., 67.

39. Ibid., 68.

40. Ibid., 83.

41. Ibid., 84.

42. Ibid., 99.

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44. Ibid., 111.

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46. Ibid., 120.

47. Alan Harris et al., *The Deflection Dilemma: Use vs. Misuse of Technologies for Avoiding Interplanetary Hazards* (Ithaca, N.Y.: Cornell University Center for Radiophysics and Space Research, 3 February 1994).

Chapter 3

Planetary Defense System

Mission and Required Capability

Before describing the capability required in a PDS, it is important to define its intended mission. Simply stated, the PDS mission is "to defend the Earth-Moon system against all Earth-crossing-object threats."[1] At this time, Planetary Defense (detecting, tracking, cataloging, or mitigating ECOs) is not an assigned or approved mission of the Department or Defense or the Air Force.

Required Capability

The capability required of a PDS varies with the scenarios that may occur. Table 3 provides four different scenarios which depend upon the path of the ECO.[2] The ECO scenario reveals time available for action, nature of action required, probabilities of detection (percentage of currently estimated known ECOs greater than 1 kilometer diameter and percentage of those yet to be detected), distances at which they will likely be detected, deflection velocities (ΔV) required to mitigate, and likely type of ECO (an ECA is an earth-crossing asteroid). An ideal PDS would provide adequate defense for all four scenarios.

One only has to watch Star Trek to imagine the ultimate system to be used to detect and mitigate ECOs—the *Enterprise*. The *Enterprise's* on-board detection systems, command, control, communications, and computer, intelligence systems, photon laser systems, and capability to travel at 10 times the speed of light would enable it to protect the earth from all but the least likely of scenarios such as multiple or large ECOs. Limits to advances in technology and spending make it unlikely that such a system would be developed by 2025.

The *Enterprise*, however, does provide an advanced system model from which we can deduce current or future systems capable of yielding similar results. Such a system can be broken down into three main subsystems: detection, C[4]I, and mitigation.

Table 3

ECO Scenarios

ECO Scenario	Time	Action	>1 km ECO	Distance (AU)	Δ V (cm/s)	ECO
1. Well-Defined Orbit	10+ Years	Long term	5/95%	2	1	ECAs
2. More Uncertain Orbit	Years	Urgent	Unknown	2	10–100	New ECAs, Short-period comets
3. Immediate Threat	1–12 Mos.	All-out effort	95/5%	0.1 (comet) 0.1–1 (ECA)	>1,000@0.1AU >100@ 1 AU	Long-period comets, Small new ECAs
4. No Warning	0–30 Days	Evacuate	Unknown	0	10–40 km/s Impact	Long-period comets, Rogue ECAs

The earlier an ECO is detected, the more time is available for mitigation action. Thus, of the three subsystems, detection subsystems appear to be the most critical at the present time. It is the first system that should be funded, researched, developed, and deployed. Fortunately, some initial steps in the correct direction already have been taken with regard to detection. The most notably has been initial components of the Spaceguard Detection Network (described in a later section). By 2025 the PDS detection subsystem must be much improved in regards to search (sky coverage), focusing speed, range, and resolution.

Command, control, communications, and computer subsystems are the glue to hold the PDS together. Advanced command, control and computers systems will be necessary to optimize scanning, tracking, and orbit determination for the detection system. Intelligence systems are necessary to determine the composition, strength, and other physical characteristics of ECOs. Advanced command, control, communications and computer systems are required to direct the mitigation systems to their targets and perform their mission. As detection capabilities improve, C^4I must keep pace with the expanding volume of data that must be shared among globally dispersed observation sites. Present coordination methods using the telephone, fax, and electronic mail for follow-up will be grossly inadequate. Follow-up notification must be immediate, and search data must be updated and shared globally in real-time. Fortunately, communications bandwidth and data storage technologies are expanding at a breathtaking rate even without the concern of planetary defense. Required system capabilities should be available prior to 2025.

Ready-to-go subsystems with ECO mitigation capabilities do not currently exist, though many scientists believe nuclear weapons could provide near-term protection with modification. Many potential nonnuclear defense subsystems have been identified in the past, and we have proposed several more, though we admit they are on the fringe between reality and imagination. Regardless of type, we are not convinced that mitigation subsystems need to be developed in the near term or even prior to 2025. It is perhaps better for us to encourage and wait for technology breakthroughs to drive the direction of these subsystems. If we develop a capable detection subsystem and it detects an ECO of concern, then a timetable for complete mitigation subsystems development and deployment will be necessary and priority for funding will be justified. By 2025 safer, cheaper, and more politically acceptable mitigation systems than the current nuclear systems should be available.

Detection Subsystems

Humanity has observed and often recorded the phenomena of comets, meteors, and meteorites throughout the recorded history, however, little was understood.

History of Detection

In 616 AD the Chinese reported the crushing of 10 people by a meteorite. The idea that comets might possibly strike the earth was first considered by Jakob Bernoulli a millennium later, in 1682. Fourteen years later, William Whiston predicted that the comet of 1680 would next return in 2255, when it would impact the earth and cause the end of the world. Nearly a century later, in 1777, Anders Lexell showed that the comet observed seven years earlier had made what is still the record confirmed closest approach to earth, little more than 1.2 million miles. And in 1801, *Ceres*, the first asteroid was discovered.[3]

Little concern with the prospect of an ECO impact seemed evident, however, until the near-earth passage of the asteroid *Icarus* in 1968. Although the orbit was carefully monitored to bring it no closer than 3.6 million miles from earth, professors at the Massachusetts Institute of

Technology challenged 21 students in the Advanced Space Systems Engineering course to propose what could be done if *Icarus*, the 13th known near-earth asteroid, happened onto a collision course with earth. At least 30 newspapers and other print media published sensationalized and often distorted accounts of the project and the circumstances of the asteroid impact. As a result, many Americans for the first time became aware of both the possibility of an ECO impact and the possibility that something could be done about it.[4] In 1980, when a new theory explained the extinction of dinosaurs due to a gigantic asteroid impact, the attention of the scientific community was at an all-time high. The concept of planetary defense began to move appreciably forward, at least in the sense of determining the level of an ECO threat.

Current Detection Programs

By 1982 the discovery rate of NEOs reached 10 each year as several systematic photographic search programs were established. The greatest leap forward thus far in the area of ECO detection occurred in 1989, when the Spacewatch program began operation. Conceived and directed by Tom Gehrels at the University of Arizona, Spacewatch incorporates modern electron charge-coupled detectors (CCD) and computers to automate much of the discovery process. Digital intensity information is read from a 2,048 x 2,048 pixel array and is used to build an exhaustive catalogue of all objects, including stars, galaxies, belt asteroids, comets, and NEOs in the image. The data is stored magnetically, and later the same night, the computer directs the 36-inch telescope back to the same area for a second image. The computer instantly compares the objects in the second image with the first, checking off each object against what is stored in the catalogue and notes any feature that only appears in one image. Finally, the computer takes a third image to verify that objects that seem to move between the first two images, continue to do so.[5] On a good clear night, as many as 600 new asteroids are discovered, and on average, one in 900 of these is a NEO.[6]

With planned improvements to the Spacewatch network including a new 1.8-meter mirror telescope at Kitt Peak and electronics upgrades in Australia and in France, Mr Gehrels estimates that if there are any 1 kilometer or larger asteroids on a collision course with the EMS, we should know of them by the year 2008. Unfortunately, though, Spacewatch will not be sufficient to entirely rule out the threat of smaller but still dangerous asteroids and of long period comets.[7]

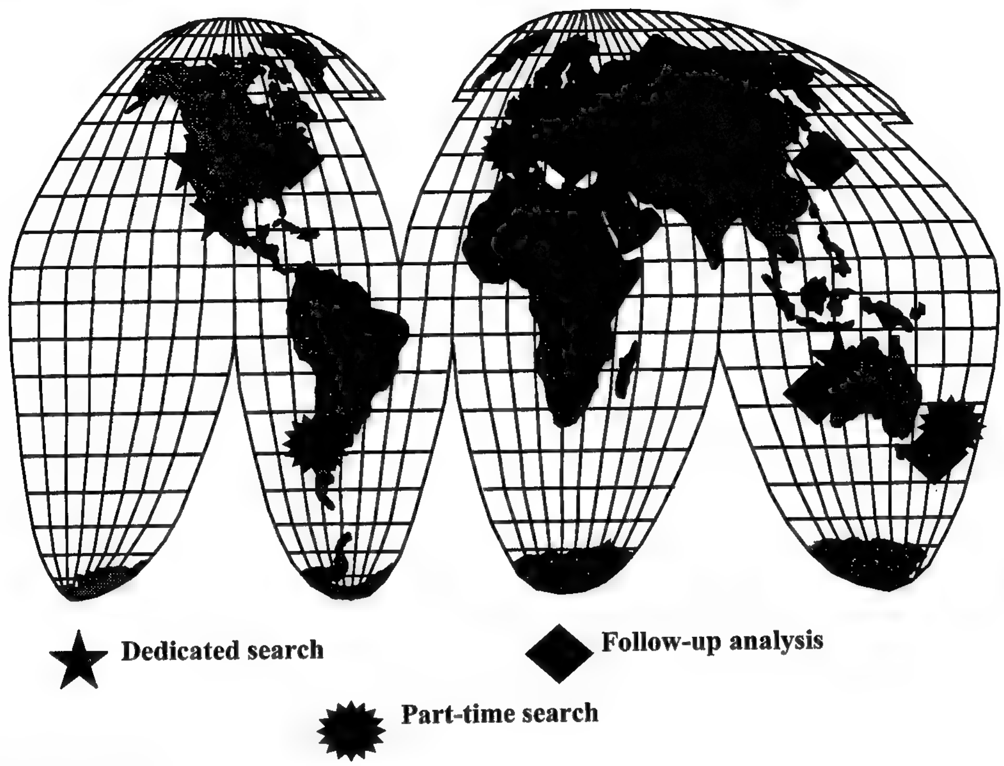
Figure 3-1 shows the locations worldwide of the four current ECO search programs. (At Palomar, California: the Palomar Asteroid and Comet Survey and Palomar Planet-Crossing Asteroid Survey surveys; at Kitt Peak, Arizona: Spacewatch; in Western Australia: Anglo-Australian Near-Earth Asteroid Survey.[8])

Note that only one survey is currently operational in the Southern Hemisphere. The 1991 *Spaceguard Survey* Workshop recommended a \$50 million up-front and \$10–15 million per-year program.[9] With six globally dispersed Spacewatch-type telescopes, scientists expect to achieve a discovery rate of one object for every two seconds of observation time.[10] (In addition to Kitt Peak and Palomar, other Northern Hemisphere observatories would be located, possibly in India and France. In the Southern Hemisphere, in addition to Australia, Chile would be an ideal site.[11])

Detection, Tracking, and Homing

The detection subsystem of the 2025 PDS is comprised of three, broad functional roles, each of which can be further subdivided into several discrete tasks. The roles, in sequence include detection, tracking, and homing.

The detection role is comprised of two tasks: discovery and discrimination. The PDS detection subsystem detects all potential ECOs at a maximum distance from



Source: *Hazards,* 129–136.

Figure 3-1. Current ECO Search and Detection Network

the EMS. Long-range detection equates to advance warning time. Advance notice of a potential impactor is the single most important variable in the PDS problem. The earlier an ECO is discovered, the more options are available to mitigate the threat. The detection system or systems should continuously search the total volume of space for all asteroids and comets that exceed a size and mass that can be assured to burn up during descent through the earth's atmosphere.

It is of great importance also to quickly determine whether the just-detected object is a true, first-time discovery, or whether it has been previously discovered, catalogued, and then lost for a period of time because of obstructions or excessive distance from earth.

The problems of long range and discrimination are not the only major detection obstacles to overcome. The volume of sky is perhaps the greatest obstacle. Present telescope capabilities only can search approximately 6,000 square degrees of the night sky each month. Total sky coverage is 41,000 square degrees.[12]

For 2025 we have specified a required capability to search the entire volume of space on a daily basis, to detect an object of a minimum size of 100 meters in diameter at a minimum distance of 2.5 astronomical units (AU) (slightly more than the average distance to the main asteroid belt between Mars and Jupiter of 2.2 AU from Earth), and to confirm within seconds whether the object is a new discovery or is an object that is already cataloged.[13] Current Spacewatch capabilities require 150 telescopes to discover all 200,000 (or more) 250-meter ECOs within 20 years and orders of magnitude more of them to discover 100-meter objects.[14] Obviously, this is not the solution. Computers must be harnessed to

modern telescopes in a way to dramatically reduce the time it takes to make initial and follow-up observations.

Tracking, the second broad role, begins as soon as it is determined that an object has the potential to impact the EMS. The tracking role encompasses the follow-up functions of astrometric analysis and the constant awareness of the object's whereabouts. Astrometric analysis refers to the precise calculation of position and velocity. These aspects are discussed in detail in the later C4I section. The tracking subsystem should strive to use an independent means of orbit calculation to confirm the initial diagnosis of an earth-crossing orbit or dangerously close passage. Calculation of an EMS threatening orbit must be completed with sufficient advance notice to still permit selection of the most benign and most cost-effective approach to mitigate the threat.

For 2025 our tracking requirements are that astrometric analysis be completed within hours of discovery, the ability to know an ECO's whereabouts at all times regardless of whether it may be visually blocked by other celestial objects in the foreground or background, the ability to track an ECO regardless of meteorological conditions and the effects of daylight and moonlight, and the ability to feed targeting information in realtime, or near real time, to the mitigation system throughout application.

The last broad role of detection is homing/results assessment. In one sense it can be thought of as targeting and battle damage assessment (BDA). However, in planetary defense, destruction of an ECO is only one possible response to the situation.

Specific 2025 tasks and requirements encompass the ability to accurately guide a spacecraft to the ECO, to observe on earth the mitigation actions as they are applied, immediate feedback of the success or failure of the mitigation action, and, if mitigation is unsuccessful or only partially successful, continued observation until successful handoff to the detection or tracking subsystem.

In summary, detection is currently the most advanced portion of the PDS by far. The seven-year-old Spacewatch program is currently searching space for 1 kilometer and larger ECOs, and all earth-crossing asteroids should be known by 2008. However, several major shortfalls exist with Spacewatch. First, the Spacewatch ECO size cut-off at 1 kilometer and greater is an order of magnitude larger than we feel can be safely ignored. Secondly, the current rate of discoveries is barely acceptable at the 1 kilometer size cut-off (given a total estimated population of approximately 2,000). To search for all objects greater than 100 meters the estimated population climbs to several hundred thousands, thus a significantly faster detection rate must be achieved.

Detection Concepts for 2025

So, how can the greater rates of discovery necessary in 2025 be achieved? One way of substantially increasing ECO discovery rates is by using the current capability of the USAF's Ground-Based Electro-Optical Deep Space Surveillance System (GEODSS) assets. It is estimated that a single GEODSS telescope could improve upon the Spacewatch program's discovery rate by a factor of 20.[15] To speed tracking solutions, increased access to the large planetary radars at Puerto Rico and California is also recommended.[16]

One 2025 concept is to employ change detection sensors. Rather than scrutinizing all objects in space, the sensors would search only for movement ("change") in space. With movement sensitivity properly gauged to eliminate distant bodies, observation devices could concentrate only on near-earth and thus potentially earth-crossing objects.[17]

How also will daily total sky coverage and constant, real-time tracking occur? Use of only ground-based optical assets is insufficient to search the total sky. While ground-based optical can currently detect 100-meter ECOs in opposition (on the side of the Earth opposite from the Sun), they are blinded when objects are in conjunction

(sun side). Emerging technologies available in 2025 should be better able to handle this problem.

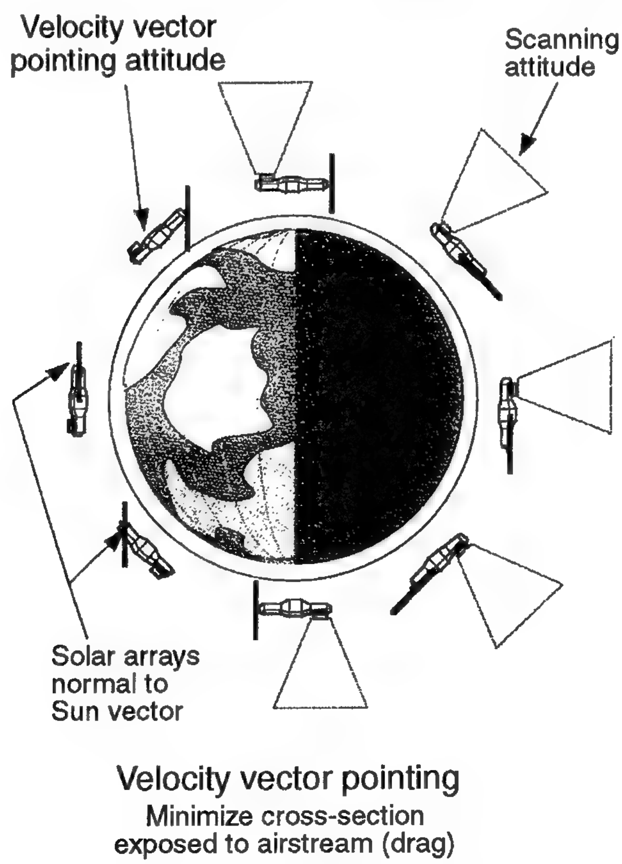
Use of space for basing space observation platforms makes good sense for 2025. While it is currently much more expensive to use a space-based platform rather than a ground-based one, the cost difference should be less pronounced in 2025, particularly when effectiveness and lack of downtime are factored in. Space-based systems will not have to deal with clouds, weather, and pollution, for example.

Figure 3-2 shows one detection concept suggested by the Lawrence Livermore National Laboratory. By placing sensors in space, operational time is substantially increased, surface weather conditions are eliminated as an obstacle to viewing faint objects, and a larger unobstructed field of view is possible.

Table 4 summarizes potential detection technologies and systems with respect to their technology availability, ECO scenario applicability, risk level, problems, maintenance requirements, and cost.

Borrowing from the *New World Vistas* study, distributed constellations of lightweight and relatively inexpensive sensing satellites could be deployed and linked to each other by laser data links.[18]

Active sensing systems on these satellites would potentially use infrared, light detection and ranging (LIDAR), radar, laser



Source: L. L. Wood, et al., "Cosmic Bombardment IV: Averting Catastrophe in the Here-and-Now," Presentation to Problems of Earth Protection Against the Impact with Near-Earth Objects (SPE-94) (Chelybinsk, Russia: Russian Federal Nuclear Center, 26–30 September 1994).

Figure 3-2. Sky Eyes—Deep Space Sentry System Concept

Table 4

Detection Technologies

System	Tech	ECO Scenario Application*	Risk Level	Problems	Maintenance	Cost in Millions of Dollars
Ground-based Optical & Radar	Now	1,2,3,4 (Detection, Tracking, Homing)	N/A	Sunlight, Weather	Low-Med	10+
Space-based Optical	Now	1,2,3,4 (Detection, Tracking, Homing)	N/A	Earth, Moon, other obstr.	N/A	TBD
Ground-based Infrared	Now	1,2,3,4 (Detection, Tracking, Homing)	N/A	Weather, Horizon	Low-Med	10+
Space-based Infrared	Now	1,2,3,4 (Detection, Tracking, Homing)	N/A	Earth, Moon, other obstr.	N/A	TBD
Ground-based Radar	Now	1,2,3,4 (Tracking, Homing)	N/A	Weather, Horizon	Low-Med	10+
Space-based Radar	2025	1,2,3,4 (Detection, Tracking, Homing)	N/A	Size, Limited Range (space loss)	N/A	TBD
Space-based LIDAR/LADAR	2010	1,2,3,4 (Tracking, Feedback)	N/A	Field of View Limits	N/A	TBD

*ECO Scenarios 1-4 are described in Table 3.

detection and ranging (LADAR), and radio array to detect the radiation and low-frequency radio emissions caused by object movement in the solar winds.

Satellite constellations might best be placed in orbits other than around the earth. For example, Aten asteroids, which threaten the earth from the sunward side, could be detected by satellites in orbit around Venus, Mars, or Jupiter or by satellites in a halo orbit around the Lagrangian point between the Earth and the Sun, or in solar orbit above the main asteroid belt between Mars or Jupiter.[19]

Command, Control, Communications, Computers, and Intelligence Subsystems

The defense of the Earth-Moon system requires a global outlook, in spite of limitations in international cooperation. *Leadership* of a planetary defense program is a critical issue which must be established both nationally and globally. However, some nations may possess the capability to unilaterally defend the planet, their own territory, or the territory of selected allies. This paper suggests a possible leadership framework. This section presents a command and control system based on that proposed framework. Command and control of a system of systems to detect and mitigate ECO threats poses many challenges—especially command relationships among international organizations.

Unilateral US Command Elements

By 2025 the United States could certainly possess the capability to defend the planet either through an expedient, ad hoc effort or through a deliberately planned, funded, and coordinated program. With either possibility

the US could take the lead by default or by its own initiative. The proposed command structure will allow the United States to unilaterally lead and execute the effective detection and mitigation of an ECO threat (fig. 3-3).

The National Command Authority (NCA) would oversee the efforts of the primary players in the PDS and coordinate their activities. This coordination would take place through a new entity, the Planetary Defense Coordination Council (PDCC). The PDCC would in turn work with the European Space Agency and the Council of International Cooperation in the Study and Utilization of Outer Space—European Agencies with similar interests and capabilities. Although American private industry and academia are not subject to the strict command relationships of federal bureaucracies, during a time of global crisis they would likely adhere to the direction of the NCA—much in the same way they did during World War II—by banding together to combat a threat to all Americans and possibly to all other humanity.

International Command Elements

The alternate futures developed for the ***2025*** study pose varying degrees of global leadership; that is, the role of the United Nations varies greatly with the alternate future. This section assumes that the UN has no strict governmental authority—only its mandate over its member nations. This situation is similar to what exists in 1996. In that light, no nation has subjugated its sovereignty to the UN. So with respect to the world powers, the UN acts with little higher authority. There is no hierarchical structure. But regional organizations such as the European Union will have increased clout as some European nations will have banded together for increased influence. Other possibilities include regional alliances in other areas of the world, including Africa, Asia, and the Middle East. Countries in these areas may form coalitions to increase their political, economic, and military power.

Command Responsibilities—US Unilateral Action

With respect to planetary defense in 2025, there will be no official global government power to unilaterally organize, develop, deploy, and operate a planetary defense system. The planet will be forced to rely on voluntary cooperation of countries for defense against ECO impacts. But under the threat of such a catastrophe, the cooperation among nations to the decisions of the United Nations probably would run akin to the cooperation of American academia and private industry to decisions of the National Command

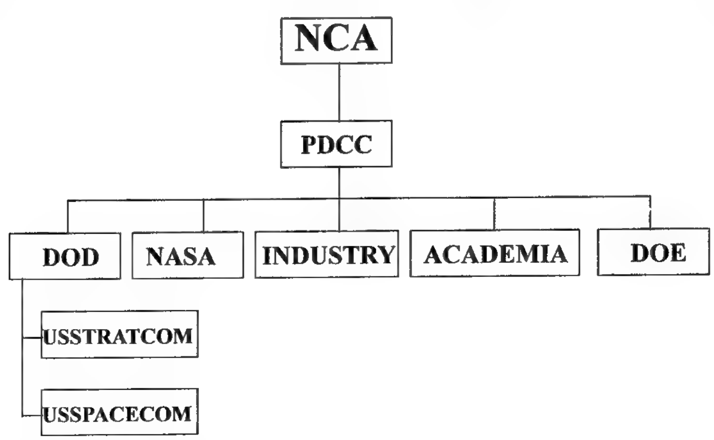


Figure 3-3. Proposed Unilateral US Command Structure

Authorities. An ECO could bring together and coalesce the nations of the world under one authority for the common good.

C^4I for Detection Subsystems

Three entities would hold primary responsibility for detection of ECOs: international observatories (generally managed by academia in coordination with government), the US Air Force, and NASA. During normal times, these entities would conduct operations without requiring significant outside direction. Should an emergency posture be required due to a possible ECO impact, sites would coordinate their efforts under the direction of the US National Command Authorities or UN as appropriate.

C^4I for Mitigation Subsystems

Two US governmental departments would be responsible for mitigating an ECO threat: the Departments of Defense and Energy. Depending on the mitigation strategy, the NCA would direct either or both of these organizations to engage the ECO as described in the mitigation sections.

Research and Development

Research and development would fall into various realms. Specifically, the DOD and DOE would perform their own organic research but also contract out to academia and private industry for inputs. In addition, technological advances developed independent of the planetary defense initiative would be incorporated into the effort.

Exploration

Responsibility for physical exploration of space has fallen primarily into the lap of NASA and its association with academia. Manned occupation of space has been a responsibility primarily of NASA. Unmanned occupation of space has spread from NASA to the Department of Defense (and the National Reconnaissance Office) and rapidly to private industry (commercial satellites). There will be a growing trend towards the civilianization and privatization of space. But for the US unilateral defense of the planet, the federal government will continue to carry the lead for space exploration.

Exploitation

Private industry will retain its role as the primary exploiter of space. But governmental development of exploitation technologies will be critical. Moon-based manufacturing and mining for federally sponsored space occupation will fuel a growing trend of the private exploitation of space. Private industry will find uses for space resources or unoccupied expanses for its own use. These technologies will be directly applicable to the exploitation of ECOs. With the development of such technologies, ECOs will become attractive sources for minerals and other valuable resources.

Command Relationships/Connectivity

Command relationships and connectivity among units within the PDS subsystems have unique requirements to consider. The detection systems operated by USAF, academia (observatories), and NASA will all be tied into Space Command headquarters rapidly providing information on ECOs. These detection systems then cross check each other to determine the accuracy of the observation and its resulting prediction.

Detection groups share information on asteroids in a centralized database, storing asteroid orbit, composition, and proximity data. Private industry would then be able to determine which bodies to seek and potentially exploit.

For the mitigation systems, connectivity is not as complicated as for the detection systems. Commander in chief, US Space Command, would possess the responsibility to engage ECOs under direction from the NCA. From a military planning standpoint, commander-in-chief, United States Space Command would periodically perform a deliberate planning process to establish a plan to engage an ECO. The CINC's cosmic

area of responsibility possesses few threats other than ECOs, and prudence dictates establishment of an operations plan to defend against potential ECO impacts. This plan would include the mitigation options described later.

Communications

Communication among the players who study the potential threat that ECOs pose is growing. In 1996 the detection system is loosely and informally integrated through the Internet. The earth's sentries scan small portions of the skies at a time and deposit their data on the Internet for other sentries to verify. Their techniques are rather basic and heavily dependent on computing power. An appropriate analogy here is the air defense network employed by the British during the Battle of Britain. Many observers deployed along the coast of the English Channel scanned the skies for formations of German planes and, once detecting them, identified their size and composition. These forward observers relayed their information to the centralized command centers where their information would be integrated into the big picture with radar and other observations.[20] So those who scan space for ECOs would benefit greatly from an improved communication network.

In 2025 the communication links among observatories will be well-meshed to cross feed and up-channel ECO data. Speed of data transfer is not a critical technology, and current capabilities are adequate to perform this function. But the integration of this information is what is lacking in 1996. Currently, no person or agency officially possesses the chartered job to collect, analyze, and disseminate all ECO data. In 2025 a system to collect and analyze the data provided by the observatories will be essential. This becomes less of a technology issue than a functional, command and control issue. In 2025 that responsibility could fall on CINCUSSPACECOM.

Communications between command facilities and space vehicles may greatly benefit from technological advances. The concept describing faster-than-light communications (currently thought to be beyond current understanding of physics) is one which would benefit, though is not necessary for, mitigation systems that must physically intercept the ECO.[21] Instantaneous communications between the earth and the space vehicle would facilitate endgame decision making—where and how to engage the ECO, for example. Not having to enlarge the space vehicle with computer hardware containing preprogrammed or automated engagement phase capabilities will allow larger payloads, faster engagement speeds, and farther engagement distances. The faster-than-light communications concept hinges on a concept of the conservation of quantum properties. If the sender alters the quantum properties of his transmitter, the receiver instantaneously is altered to compensate for the change in quantum properties.

Additionally, very high rate (gigabyte per second) communications for data relay would greatly benefit deep space control of intercept vehicles. Combined, these two concepts of high-speed and high-rate communications could have far-reaching effects.

Computers

Probably the biggest area in which great strides can be made is in the computer processing of observation data. The degree volume of space scanned is limited by scan resolution and processing capability. Faster computers coupled to more capable telescopic devices allow larger sky volumes to be searched for ECOs. Comparing new scans with archive scans at resolutions required for early detection of ECOs requires rapid database management tools and sophisticated analysis programs. In 1996 the shift from photographic to digitized techniques is almost complete. By 2025 the expansion of archive data and advances towards finer scan resolutions will make detection of ECOs far more complete and accurate.

Improved computing capabilities is also important in the astrometry realm.

Astrometry currently relies upon optical and radar for the follow-up tracking that permits refinement of the orbit necessary to identify an ECO. With better orbit-calculating models that account for orbit perturbations induced by planetary gravity (e.g., by Jupiter) and with better computing power (e.g., more significant digits), orbits can be predicted more accurately and farther into the future than with current systems. The orbital chaos contributed by Jupiter's gravitational pull to the mechanical calculations can be minimized by better modeling and greater computational power. Also, in 2025 we anticipate a combination of ground- and space-based remote sensing devices for astrometric calculations. On the ground there likely would be optical (telescope) and radar devices; in the air there would likely be optical (Hubble-like) telescopes, radar, radio array, infrared, LIDAR, and LADAR sensors.

Finally, as the database of main belt asteroids grows, data management becomes critical. Keeping track of hundreds of thousands of asteroids and comets calls for improved computing power, faster processing, and larger memory. Fortunately, this power appears to be achievable in time.

As chip technology improves, memory capacity surpasses the 1 gigabyte threshold, providing an enormous capacity to store huge amounts of data. But along with these advances, the chips and their ability to perform becomes more susceptible to space radiation. Space vehicles using these advanced chips will require hardening from cosmic radiation.[22]

Intelligence

Much intelligence is required regarding NEOs, but relatively little is presently known. This intelligence becomes vitally important to decide which mitigation system(s) can best be used against them and to predict the probability of mitigation success.

Specific intelligence necessary for all NEOs includes, but is not limited to, individual physical shape, size, mass, structure, surface and interior material compositions, brittleness, terrain, velocity, and inherent motion (e.g., spinning or wobbling). Specific intelligence necessary for targeted ECOs includes the aforementioned properties and particular weak points and maybe landing sites.

Several satellites have been used to perform NEO flybys, either as primary or secondary missions. Much data has been obtained; however, there is much more to be gained. The recently launched Near Earth Asteroid Rendezvous (NEAR) satellite will rendezvous with an asteroid to characterize its physical and geological properties (elemental and mineralogical composition, density, shape, spin state, interior structure, and surface morphology).[23] Other planned satellite missions include *Clementine II*; a comet rendezvous mission by ROSETTA—a European Space Agency program; Imaging of Near Earth Objects (INEO)—an NEO flyby mission by the German Center of Applied Space Technology and Microgravity; and a yet-to-be-named near-earth asteroid rendezvous mission by the Japanese Institute of Space and Astronomical Science (ISAS).

Clementine II is a congressionally directed technology demonstration satellite designed to test state-of-the-art sensors, components, and subsystems in the deep-space environment. Presently, the directed baseline mission is to fly by three near-earth asteroids (NEA) in quick succession. Several hours prior to the NEA flyby, a small (less than 20 kilograms) probe will be released from the mothership and directed to intercept the asteroid using onboard autonomous navigation techniques.[24]

The planned ISAS satellite will map the surface and hover within one foot of an asteroid.[25] These and other missions are of critical importance if our mitigation systems are to be designed to work effectively. Other missions are suggested by various authors.[26]

Table 5

C^{4}I Subsystem Characteristics

System	Tech	ECO Scenario Application*	Risk Level	Problems	Maintenance
C2 for Detection Systems	Now to 2025+	1,2,3,4	Low	Large volume of sky to scan	Low-Med
C2 for Mitigation Systems	Now to 2025+	1,2,3,4	Low	High-speed intercept of ECO	Low-Med
High-Speed High-Memory Computers	Now to 2025+	1,2,3,4	Low	Requires precise calculation of ECO orbits	Low-Med
Communications	Now to 2025	1,2,3,4	Low	Relatively few	Low-Med
Intelligence-gathering sensors, systems	Now to 2025+	1,2,3,4	Low	Requires detailed knowledge of ECO properties	Low-Med

*ECO Scenarios 1-4 are described in Table 3.

C^{4}I Summary

Table 5 summarizes the technical hurdles that must be overcome to implement the ideas outlined in this section effectively. Overall, there are few showstoppers that prevent the implementation of a workable C^{4}I planetary defense subsystem. Cost of the C^{4}I subsystem is relatively low. Current systems and capabilities are nearly sufficient to perform the mission.

Mitigation Subsystems

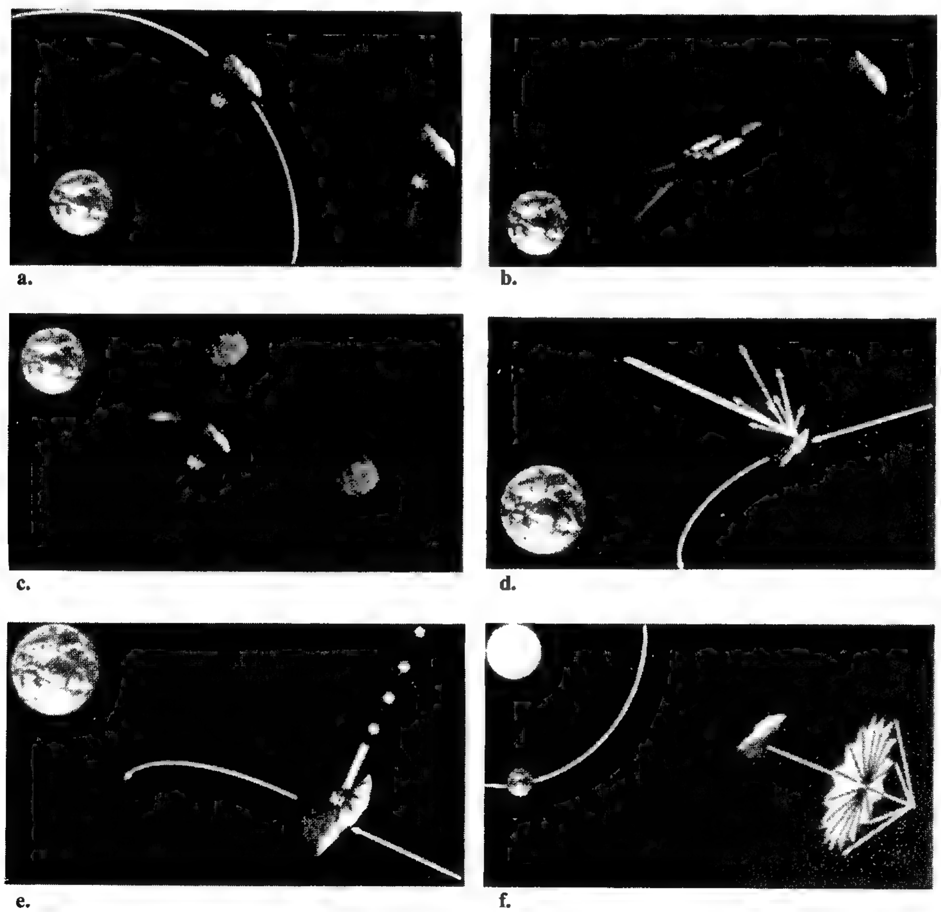
Potential mitigation subsystems are as numerous as there are science fiction novels, ranging from near-current capability to the near impossible. Mitigation subsystems typically fall into two categories—those that destroy the ECO to the point where it is no longer a hazard and those that deflect the ECO such that it would not impact the EMS. Primary factors affecting the suitability of the mitigation subsystem are the distance at which engagement with the ECO is desired, shape, size, composition, and inherent motion (e.g., spin) of the ECO. (Note: These "primary factors" will be mentioned several times in our discussion.) Popular potential mitigation subsystems addressed by current literature include, but are certainly not limited to, rocket propulsion systems; rockets with chemical, nuclear, or antimatter warheads; kinetic energy systems; high-energy lasers; microwave energy systems; mass drivers/reaction engines; solar sails; and solar collectors as shown in figure 3-4.

In addition, we propose several new ideas, including biological/chemical/mechanical ECO eaters, supermagnetic field generators, force shields, tractor beams, and gravity manipulation (fig. 3-5).

Table 6 summarizes the aforementioned mitigation systems according to technology, ECO scenario applicability, risk, potential problems, required maintenance, and cost. Evaluations are provided by the authors based on their limited knowledge of the potential systems at the present time, similar evaluations provided in various literature, and likely availability by 2025.[27] Costs do not reflect added cost to transfer systems into space (other than rocket-based systems) or manned operations to assemble or operate systems in space unless otherwise noted. Maintenance requirements and estimated cost for some systems are not provided because they are too far beyond current technologies to provide this data.

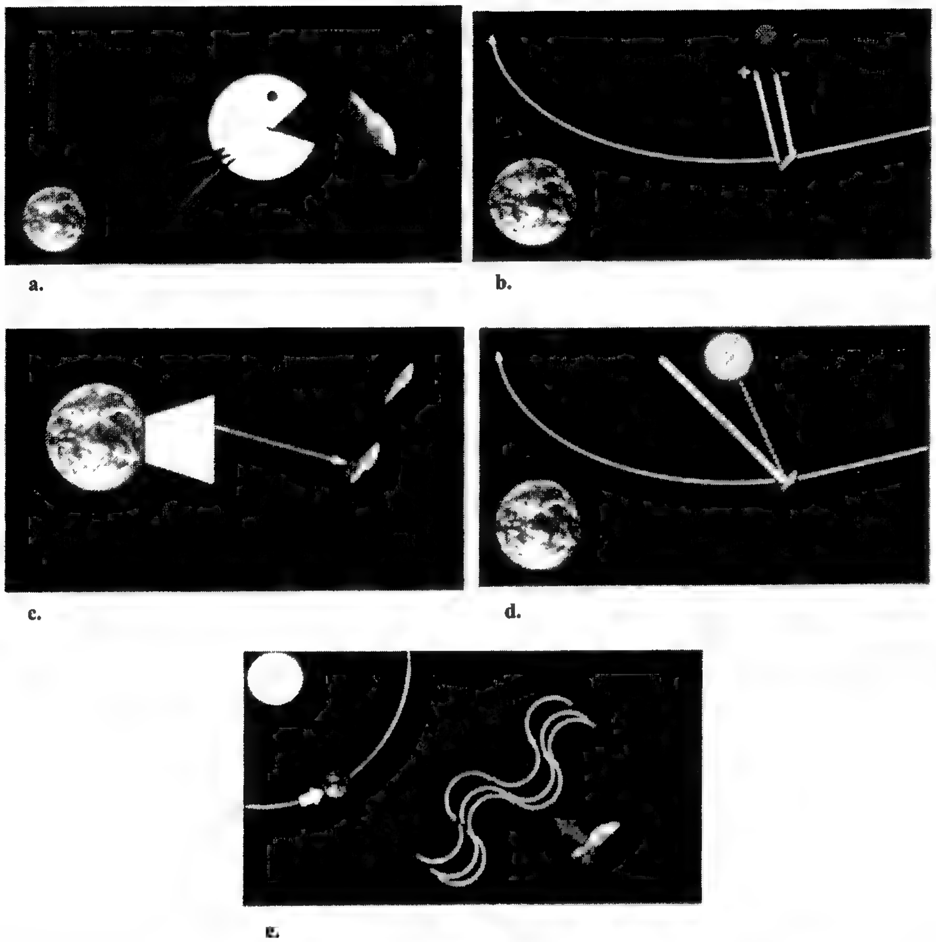
Rocket propulsion systems could be employed directly to guide an ECO out of its EMS-crossing orbit. Further, many of the subsequently discussed defense systems require delivery to or near the ECO and thus would require a space lift system to get them there. A variety of propulsion systems including, but not limited to, chemical, nuclear, antimatter, laser pulse detonators, ion-electricity, spark gun, super orion, DHe_3 fusion drivers, and magnetohydrodynamics have been proposed by various authors.[28] These systems range from current capability to possible capability by 2025. (It is not the intent of this paper to discuss the variety of propulsion systems in detail, as they are a topic of many other studies.) The main problem with the direct method would involve attaching the rockets to the ECO. Range is a relatively simple scale-up problem for existing propulsion systems or a change to advanced propulsion systems. Intercept capability has been improved for missile systems recently primarily due to research in strategic defense initiative (SDI) and theater missile defense (TMD). Safety issues for launching larger rockets and some of the advanced propulsion systems must be considered. Development costs are estimated to range from \$5 to \$20 billion.[29]

Rockets employing chemical (conventional) or nuclear warheads already exist. They fall short, however, in terms of range, megatonnage of yield, and ECO intercept capability.



Legend: a. Rocket Propulsion; b. Rocket-Delivered Chemical/Nuclear/Antimatter Warheads; c. Kinetic Energy; d. Directed Energy; e. Mass Driver; f. Solar Sail

Figure 3-4. Potential Mitigation Subsystems



Legend: a. Biological/Chemical/Mechanical ECO Eaters; b. Supermagnetic Field Generators; c. Force Shields; d. Tractor Beams; e. Gravity Manipulation

Figure 3-5. New Potential Mitigation Subsystems

Many scientists believe that nuclear weapons systems are currently the only feasible method for planetary defense for most situations, and much analysis and research has gone into the subject. Depending on the primary factors, the rocket(s) would be launched to deflect the ECO that it would not impact the earth or to fracture the ECO into sufficiently small pieces. The rockets may be earth- or space-based. Actual employment of the weapon system would involve either a single or multiple proximal burst(s), surface burst(s), or subsurface burst(s). In general, in the deflection mode, proximal bursts minimize the potential danger of fragmentation of the ECO but at a penalty of greater required yield when compared to surface or subsurface bursts. Surface bursts could be used to deflect or destroy the ECO. Subsurface bursts would be used only to fragment the ECO. Table 7 lists the required nuclear explosive yields necessary to perturb the velocity of various size asteroids by 1 centimeter per second (sufficient time if a decade is available to achieve deflection), or, in the case of sub-surface bursts, to fragment the asteroid into pieces less than 10 meters in diameter, as estimated by T. J. Ahrens and A. W. Harris.[30]

Table 6

ECO Mitigation Systems

System	Tech	ECO Scenario Application*	Risk Level	Problems	Maintenance	Cost in billion (Dollars)
Propulsion	Now to 2025+	1,2,3,4	Low-High	Safety	Low-High	5–20
Nuclear/Chemical/ Antimatter Explosives	Now/Now/ 2025+	1,2,3,4	Medium/ Low/High	Space Treaties, ECO Breakup/ Efficiency, Storage	Low/Low/High	1+ 1+ 10+
Kinetic Energy	Now	1,2,3,4	High	Long lead, ECO Breakup	Low	10+
Laser	2005	1,2,3	Low	ABM Treaty, High power requirements	Medium	10–20
Microwaves	2015	1,2,3	Low	System size, power requirements	High	20+
Mass Driver/ Reaction Engine	2015	1,2	Low	May require manned assembly	Medium	5+
Solar Sails	2025	1,2,3	Low	May require amnned assembly	Medium	1+
Solar Collectors	2025	1,2,3	Low	May require manned assembely	Medium	5+
ECO Eaters	2025	1,2	Low	Slow, quantities required	None	1+
Magnatic Field	2025+	1,2,3	Low	High-power requirements	TBD	TBD
Force Shield	2020	1,2,3,4	Low	Environmental effects	Low	TBD
Tractor Beam	2025+	1,2,3,4	Low	Undeveloped technology	TBD	TBD
Gravity Manipulator	2025+	1,2	Low	Undeveloped technology	TBD	TBD

*ECO Scenarios 1-4 are described in Table 3.

Table 7

Nuclear Charges Required for Various Asteroid Employment Scenarios

Asteriod Size	Proximal Burst (With radiative efficiency of 0.3–0.03)	Surface (With radiative nuclear charges*)	Subsurface (Optimally burried charges)	Subsurface-soft rock (Optimally burried charges)	Subsurface-hard rock (Optimally burried charges)
0.1 km	0.1–1 kt	500 kg	800 kg	1 kt	3 kt
1 km	100 kt–1 mt	90 kt	22 kt	1 mt	3 mt
10 km	100 mt–1 gt	200 mt	0.6 gt	1 gt	3 gt

*Based on extreme extrapolation of the effect of gravity on gravity-dependent cratering.

V.A. Simonenko and others estimate a 1 MEGATON nuclear charge detonated on the surface can deflect a 300 meter astral assailant if it is engaged at a distance about equal to the earth's orbital radius.[31] Roderick Hyde and others estimate that hundreds of gigatons of energy will be required to deflect an asteroid of 10 kilometers by about 10 meters a second at a time greater than two week's distance from earth.[32]

Table 8

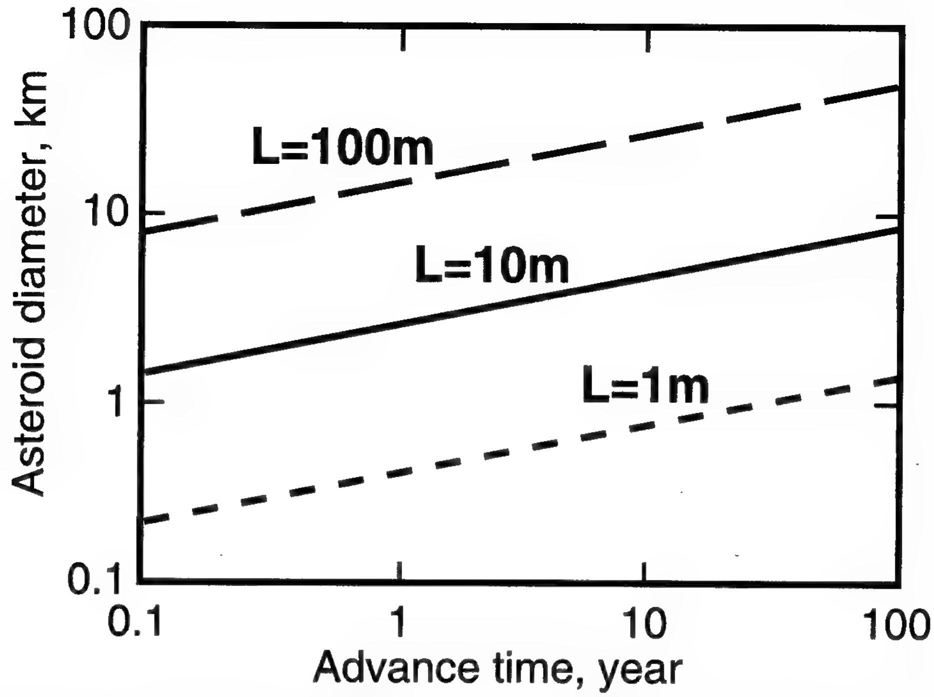
Yield versus Mass for Nuclear Explosive Devices

Yield	Mass
1 mt	0.5 ton
10 mt	3–4 ton
100 mt	20–25 ton
1,000 mt (1 gt)	120–150 ton

Other scientists have done similar work.[33] Table 8 provides necessary payload mass to be delivered for required nuclear yields.[34] Note that we have extrapolated the mass required for a 1,000 megaton yield.

Additional megatonnage is a relatively simple scale-up problem. Safety concerns exist. Though improbable, any accident with a nuclear weapon of the size to be used, particularly during launch, obviously could be catastrophic. Technically, developing and deploying such a nuclear system is possible now at an estimated cost of $1+ billion.[35] Use of antimatter or other warheads, such as the proposed concept of a high-explosive driven particle beam warhead, is technologically not likely to be available until beyond 2025.[36] Estimated costs for antimatter warhead systems exceed $10 billion.[37]

Kinetic energy systems would use the mass and velocity of a projectile to either shatter the ECO into smaller pieces or redirect its path. Projectiles must be of sufficient energy and size to do the job. Projectiles would be a rocket, rocket-powered object, or, as a bizarre twist, even another asteroid. The major problem associated with this system is the relatively large mass of projectile required to be propelled at the ECO. Heavy spacelift systems would be required. Figure 3-6 describes the capability of 1-, 10-, and 100-meter-diameter projectiles.[38] According to J. C. Solem and C. M. Snell, kinetic energy deflection is practical only for ECOs of 100 meters or less in diameter for the case of terminal intercept of less than one orbital period warning; furthermore, it may be an effective method for ocean diversion of rocky asteroids smaller than 70 meters in diameter if the interceptor encounters the ECO at a distance of greater than 1/30 AU.[39] Ahrens and Harris agree that it is feasible to deflect 100-meter ECOs by way of direct impact.[40] Another variation of the kinetic energy solution would be to use a



Note: The three lines represent impacts by projectiles of 100, 10, and 1 meters in diameter and show how large an asteroid may be deflected from a collision with the earth as a function of the time elapsed between the impact on the asteroid and the predicted collision with earth.

Figure 3-6. Capability of Kinetic Energy Deflectors

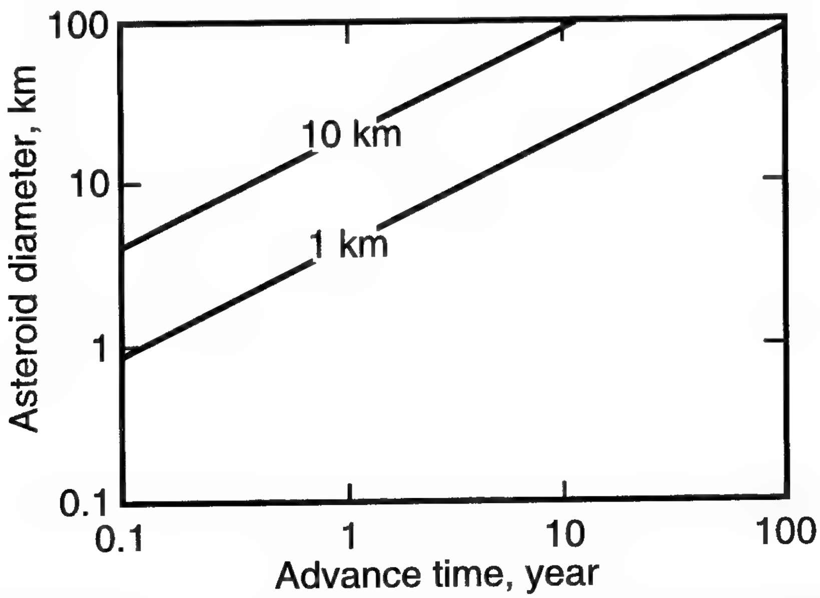
system of small penetrators, arranged in lattice fashion, and placed in the path of the ECO which would use the kinetic energy of the ECO against itself.[41] Costs of kinetic energy systems are estimated to exceed $10 billion.[42] At first glance, high-energy lasers would appear to be a feasible defense system against ECOs, especially prior to 2025, at the current rate of laser development. Laser systems, however, are currently limited by extreme size, expense, and atmospheric beam divergence.[43] A sufficient ground-based or space-based laser would offer the shortest response times to the ECO threat.

A laser deflection system based near the Earth or Moon is well suited to the deflection of small bodies (100–200 meters in diameter) which are more difficult to detect at large distances from Earth.[44] Employment depends on the primary factors, especially the composition of the ECO, but regardless of composition, the laser would have to either cut the ECO into smaller pieces, heat it up until it explodes from internal pressure, melt it, or deflect it by imparting impulse energy on it. The latter option appears to be the most feasible. The required power for a system capable to accomplish such feats may be well beyond current capability, especially at the ranges at which the system must work if the system is earth-based. B. P. Shafer and others estimate that an earth-based laser beam output necessary to match the energy of a 1 megaton nuclear blast (deflection mode) is roughly 1 gigajoule(s) for an uninterrupted period of 12 days, neglecting beam losses.[45] Such a laser would require relatively enormous optics, but innovative large optics technologies are currently being investigated, such as 20+ meter thin film mirrors and other techniques. New technology phase conjugation correctors, shorter wavelengths, more accurate pointing and tracking techniques will also

increase the feasibility of such systems.[46] Longer radiation times or a more powerful laser would be required to account for beam losses. Space-based systems may reduce required optics size and beam losses and thus the power required, but these advantages may be offset by the cost associated with delivering and maintaining such systems in space. Development costs for an earth- or space-based system are estimated to range from $10 to $20 billion.[47]

Microwave energy systems are similar to lasers in that they are also directed energy systems. Phased array antennas would be used to focus microwave beams which would then deflect the ECO by, depending on the composition of the ECO, heating the surface or subsurface, resulting in reaction to the resultant expanding vapor plumes. Narrow band systems have a long way to go to achieve power required, but introduction of new materials is expected to improve high-voltage performance, cathode emission, and pulse lengths.[48] Ultra-wide band (UWB) class systems with greater power capability are current technology, but the energy flux delivered is not concentrated enough. A UWB source capable of delivering 25 gigawatts (gW) of peak power has been demonstrated, a 100 gW pulser will be demonstrated within the year, and a terawatt machine is on the drawing board.[49] The likely limiting factor of these systems is the massive antenna arrays that would be required. To focus microwaves on a spot 100 meters in radius at a distance of only .003 AU requires a phased array 160 kilometers in diameter. The total radiated power would require 10 gW for energy fluxes on the asteroid to reach 10^6 Wm^{-2}, which would lead to sufficient deflection.[50] To deflect ECOs greater than 100-200 meters in diameter, the system would likely have to be space-based. Estimated development costs exceed $20 billion.[51]

A mass driver and reaction engine requires interfacing with the ECO in such a manner that it can be anchored to the surface. Reaction mass must be removed from the ECO then propelled into space in the required direction, resulting in a propulsive effect in the opposite direction.



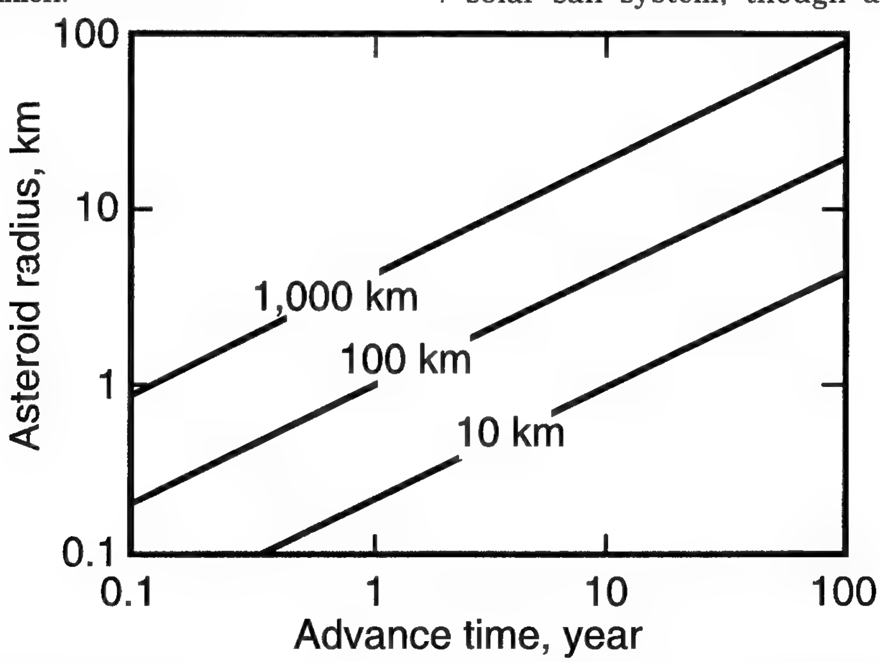
Note: The mass driver is categorized by the diameter of a solar collector (at 1 AU) needed to supply operating power at 10 percent overall efficiency. The lines for 1 and 10 km diameter circular collectors show that modest-size systems may be capable of diverting asteroids in the 1 to 10 kilometer range.

Figure 3-7. Capability of Mass Drivers

Since the thrust to be developed is proportional to the mass removal rate and the ejection velocity, a power plant able to provide sufficient energy (estimated at 300m/s) is required; a nuclear plant or a solar energy plant would suffice.[52] Figure 3-7 depicts the capability of a mass driver using a solar energy plant operating at a realistic 10 percent efficiency with solar collectors of 1 and 10 kilometers in diameter at a distance of 1 AU from the ECO.[53] This system is favorable for ECOs at greater distances, which allow for greater time to influence. The mass driver system itself is within current technology. The long pole in this system appears to be the ability to rendezvous with the ECO, attaching the mass driver and ejecting the mass in the desired direction. This would be especially difficult if the ECO has an unstable surface or any inherent motion such as a spin. Manned installation and operation may be required. Estimated development costs exceed $5 billion.[54]

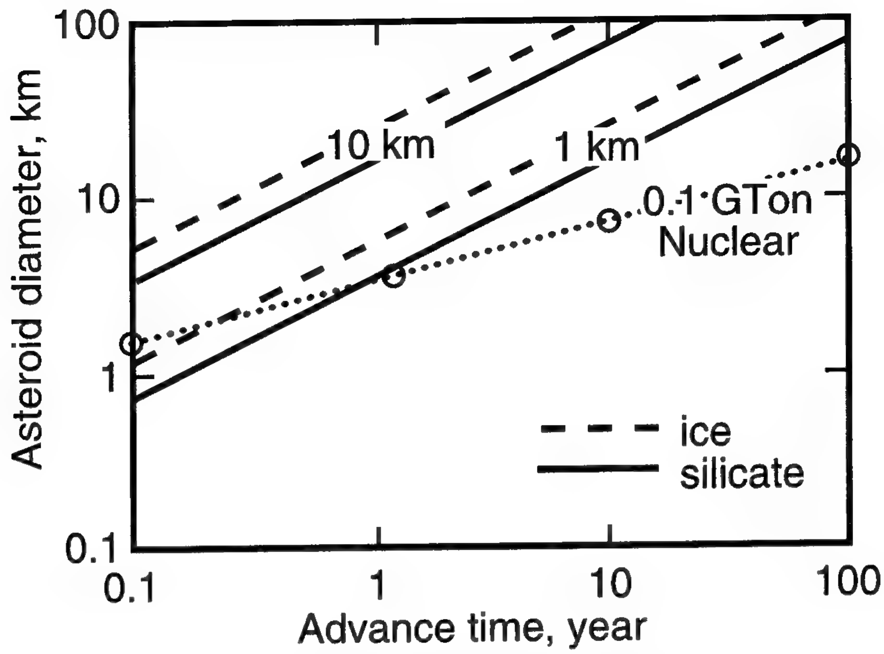
Solar sails would be employed in a manner similar to a sail on a sailboat or a paraglider using solar radiation as "wind." The required sail sizes are enormous even to deflect relatively small ECOs (fig. 3-8).[55] Further, solar sails would have to be attached to the ECO, and manned assembly likely would be required. Though this system probably has the lowest risk and would be the most environmentally friendly, the space construction effort is likely beyond our capability for at least several decades or more. The estimated cost for developing solar sails is $1–2 billion.[56]

Solar collectors would use solar sails as a solar energy collector, focus light onto the surface of the ECO with a secondary mirror, and generate thrust on the ECO from the vaporization of the ECO. It is estimated that a solar collector of 1 kilometer in diameter could deflect ECOs up to 3.4 km if continuously operated for a year.[57] Figure 3-9 summarizes the capabilities of solar collectors.[58] Solar collectors suffer from similar problems as the solar sail system, though also require



Note: The three lines are for different solar sail diameters. Even small asteroids require enormous solar sails (10–1,000 km in diameter) which, along with the technical difficulty of tethering them to the asteroid, makes such a deflection system look very unfavorable.

Figure 3-8. Capability of Solar Sails



Note: This plot shows the diameter of the asteroid (or comet) that can be deflected as a function of the time before impact. The pairs of solid and dashed lines are for silicate and icy bodies, respectively, that can be deflected by either 1 km or 10 km diameter solar collectors. The heavy dotted curve with representative points is for the nuclear stand-off scenario employing a 0.1 gt neutron bomb with an (optimistic) assumed conversion of 0.3 into neutron energy.

Figure 3-9. Asteroid Deflection Capabilities of Solar Collectors versus Nuclear Weapons

additional hardware. Manned assembly and operation also would likely be required. Costs for development of the system are estimated to exceed $5 billion.[59]

Biological/chemical/mechanical ECO eaters, as the name suggests, would "eat" ECOs.[60] Since this would likely be a slow process, all primary factors must be considered, but the composition of the ECO is most important, as these systems would only work on particular compositions. Biological/chemical/mechanical eaters would have to digest or react with the ECO material in such a manner to produce primarily a gas which would result in a net loss of mass of the ECO, or to fracture the ECO into smaller pieces, or to make the ECO more susceptible to destruction by the earth's atmosphere. The mechanical eater would have to fracture the ECO or to make the ECO more susceptible to destruction by the earth's atmosphere. These types of systems may have more success on comets, which are known to contain large amounts of ice. Stony/metallic asteroids would be more difficult to attack but not impossible. The biological and chemical agents are not envisioned to be exotic, and some related research has been done for other purposes. A related, though more unlikely proposed concept, is a chemical morphing system, which would change the physical characteristics of material.[61] These systems would have to be deposited on the surface of an ECO in sufficient quantities to have an effect on them. This would probably require heavy spacelift system with the chemical/biological agent as the payload/warhead. The mechanical systems may have to be more complex. Self-replicating mechanical systems have been envisioned.[62] There may be safety issues associated with accidental release of potentially toxic or otherwise dangerous biological/chemical eaters. Cost estimates are unavailable.

Supermagnetic field generators could be effective against iron containing ECOs, though ineffective against comets. In its simplest terms, this system would be a magnet in space activated to attract or repel an ECO out of its orbit. The system could be based on the moon, or it could be a stand-alone satellite system, or even deployed on a "captured" asteroid. Potential electromagnetic interference with earth-based electrical systems or satellites systems and environmental damage on the earth may further reduce the utility of such a system close to earth. The required power and likely bulk of such a system make it unrealistic at the present time. Heavy space lift may be required. No research was discovered regarding such a system. The idea is presented for further investigation. Estimated costs are unavailable.

Star Trekian force shields are a figment of our imagination, but if perfected they would be the ideal system against ECOs. We currently have a pseudoforce shield for the earth—our atmosphere—effective enough to repel or destroy ECOs up to about 50 meters (stony asteroids) and 100 meters (comets) in diameter.[63] We are concerned with ECOs of larger size. Perhaps temporarily augmenting our atmosphere by changing its characteristics or extending it out further would enable us to mitigate larger ECOs. (Once again the concept of chemical morphing may apply.) Ionizing a path in the atmosphere to an asteroid may induce destructive lightning strikes, though the effects are debatable. If we can cause holes in the ozone, we ought to be able to do similar things in reverse. Potential effects on the earth's environment would be of great concern. No dedicated research was discovered for such a system. The ideas are presented for further investigation. Development costs are unknown.

A tractor beam is a system common in science fiction stories, but an equivalent system may not have to be limited to fiction. The similar system would create a vacuum greater than that of space or implosion rather than explosion to move the ECO out of its orbit. No research was discovered regarding such a system. In general, it is beyond the present understanding of physics. The idea is presented for further investigation. Estimated costs are unavailable.

Similar to a tractor beam is a gravity manipulator. If we can manipulate, or somehow take advantage of the gravity of the Earth, the Moon, or other celestial bodies such as black holes (with enormous gravitational fields), we can perhaps affect the orbit of an ECO.[64] A captured asteroid of sufficient mass could be steered to a position where its gravitational pull could be used against ECOs. No research was discovered regarding such a system. In general, it is beyond the present understanding of physics. The idea is presented for further investigation. Estimated costs are unavailable.

Concept of Operations—A Three-Tier System

To defend the EMS from ECOs, our concept of operations proposes a three-tier PDS to be deployed by 2025. The far tier would be forward deployed in or above the asteroid belt, the midtier deployed somewhere between the asteroid belt and the EMS, and the near tier deployed within the EMS (Earth, Moon, or space-based). Each tier would have overlapping ranges and capabilities. Such a system would allow us to mitigate all four ECO scenarios. Further, with such a system, we would have maximum warning times, the ability to intervene at the earliest possible times, and, in some cases, the ability to reengage the ECO should the far and/or midtier(s) fail. Finally, such a system would take advantage of the best available subsystems for each tier. Table 9 summarizes our proposed three-tier PDS based on expected development of technologies at the times of expected deployment. Figure 3-10 provides a notional picture of the three-tier proposal. As time goes on and technologies expand, new systems undoubtedly will be more effective and less costly and may replace the

Table 9

Three-Tier PDS

Tier	Deployment Zone	Detection Subsystem(s)	C^4I Subsystem(s)	Mitigation Subsystem(s)
Near	Within EMS	EMS-based optics, radar, and infrared	Primarily conventional earth-based	EMS-based rockets with nuclear warheads
Mid	Between EMS & Jupiter Asteroid Belt	Space-based optics, radar, radio array, infrared & LADAR	Conventional earth- and space-based	Space-based kinetic energy systems
Far	Within or around the Main Asteroid Belt between Mars and Jupiter	Space-based miniture remote sensing satellite constellations	Conventional Earth and space-based & forward-deployed comm. relay satellites	Space-based laser systems

recommended systems. Figure 3-11 is a proposed research, development, and deployment timeline for a three-tier PDS.

Each tier would be developed sequentially from near to far, with the detection systems developed and deployed first in parallel with and followed by C^4I systems and in parallel with and followed by mitigation systems.

Such a time line allows us to detect potential ECOs and verify the need for mitigation systems prior to their deployment. Further, such a system would allow us to be protected from all ECO scenarios at the earliest possible time with the near tier, while allowing the technological advances and cost reductions to allow us to deploy the more challenging mid and far tiers in the future.

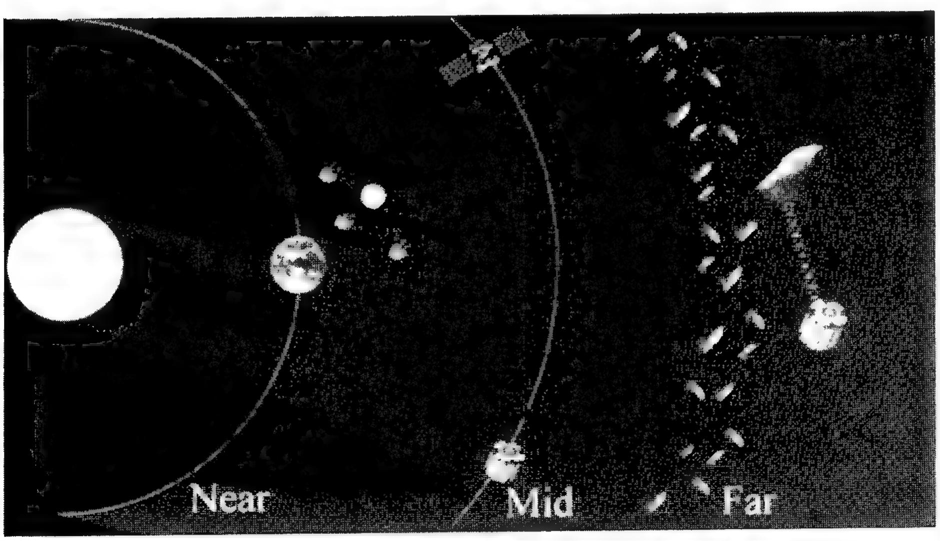


Figure 3-10. Proposed Three-Tier PDS

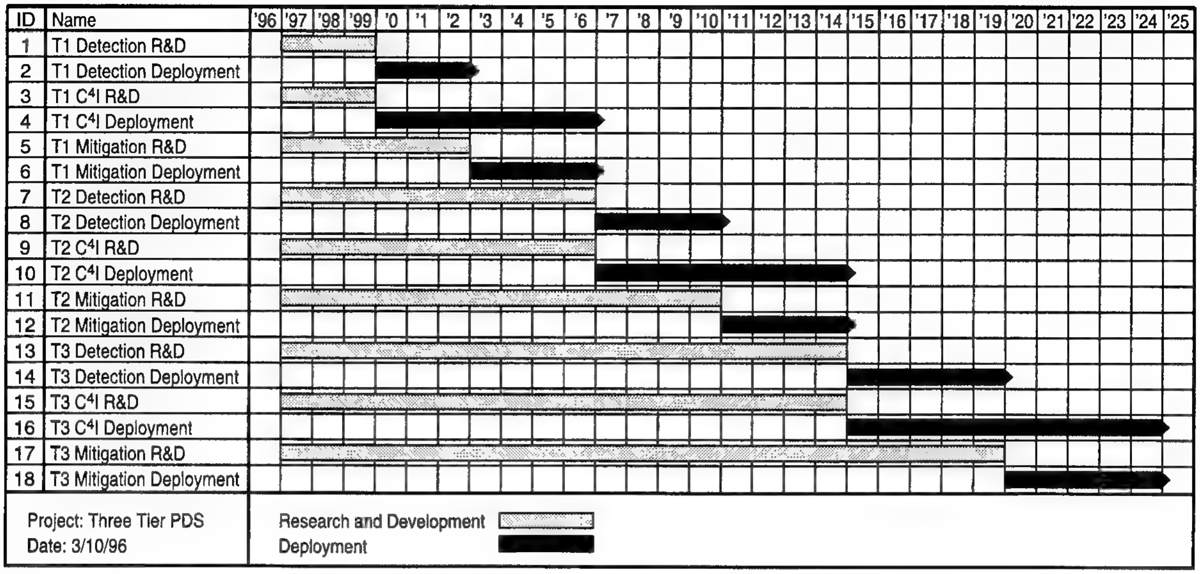


Figure 3-11. Proposed Three-Tier PDS Research, Development, and Deployment Time Lines

Notes

1. Planetary Defense System (PDS) Mission Statement based on consensus by the ***2025*** Planetary Defense team (Team B).

2. *Proceedings of the Near-Earth-Object Interception Workshop*, eds. G. H. Canavan, J. C. Solem, and J. D. G. Rather (Los Alamos, N. Mex.: Los Alamos National Laboratory, 1992), 85. We have modified the table.

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5. Ibid., 79.

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11. The NASA Ames Space Science Division, 8.1.

12. Ibid., 5.1.

13. Ibid., 5.3.

14. Lewis, 212.

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19. *Proceedings of the Near-Earth-Object Interception* Workshop, 238.

20. *Air Superiority*, B. F. Cooling, ed. (Washington, D.C.: Center for Air Force History, 1994), 115–78.

21. ***2025*** Concept, No. 200013, "Quantum Effect Communications," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

22. Ibid.

23. A. F. Cheng et al, "Missions to Near Earth Objects," in *Hazards Due to Comets and Asteroids*, ed. Tom Gehrels (Tucson, Ariz.: University of Arizona Press, 1994), 651–69.

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27. *Proceedings of the Near-Earth-Object Interception* Workshop, 234; H. J. Melosh, I.V. Nemchinov, and Yu. I. Zetzer, "Non-Nuclear Asteroid Diversion," in *Hazards Due to Comets and Asteroids*, ed. Tom Gehrels (Tucson, Ariz.: University of Arizona Press, 1994), 1111–31.

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37. *Proceedings of the Near-Earth-Object Interception* Workshop, 234.

38. Melosh, Nemchinov, and Zetzer, 1116.

39. Solem and Snell, 1030–32.

40. Ahrens and Harris, 904.

41. Hyde et al.

42. *Proceedings of the Near-Earth-Object Interception* Workshop, 235.

43. *New World Vistas* (unpublished draft, the space applications volume), 113.

44. Melosh, Nemchinov, and Zetzer, 1130.

45. Shafer et al., 965.

46. *New World Vistas*, (unpublished draft, the space applications volume), 81.

47. *Proceedings of the Near-Earth-Object Interception* Workshop, 234–35; *New World Vistas*, (unpublished draft, the directed energy volume), 24. USAF Scientific Advisory Board estimates laser energy costs at $1–$2 per joule up to the megajoule range.

48. *New World Vistas*, (unpublished draft, the directed energy volume), 59.

49. Ibid.

50. Melosh, Nemchinov, and Zetzer, 1129–30.

51. *Proceedings of the Near-Earth-Object Interception* Workshop, 234. The directed energy cost was doubled to account for the large phased array required.

52. Melosh, Nemchinov, and Zetzer, 1117–18.

53. Ibid., 1119.

54. *Proceedings of the Near-Earth-Object Interception* Workshop, 234.

55. Melosh, Nemchinov, and Zetzer, 1120.

56. *Proceedings of the Near-Earth-Object Interception* Workshop, 234.

57. Melosh, Nemchinov, and Zetzer, 1125.

58. Ibid., 1126.

59. *Proceedings of the Near-Earth-Object Interception* Workshop, 234. This figure was obtained by averaging the cost of solar sails and the cost for directed energy systems.

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Chapter 4

Dual-Use Benefits

A PDS system has many potential dual-use capabilities, with or without modification, such as earth and space surveillance, space debris detection and mitigation, ballistic missile defense, and as a space-based offensive weapons system. The overall system is, however, only one of many benefits of a decision to embark on a PDS research, development, and deployment effort.

The technologies required for the PDS would be, in of themselves, major benefits of such a program. Indeed, revolutionary deep-space detection methods, quantum communications, ultra-fast computer processing, large data-storage capabilities, high specific impulse propulsion, high kinetic energy systems, high power-directed energy systems, mass driver/reaction engines, solar sail and collector systems, chemical, biological, and mechanical "eaters," magnetic and force field generation, tractor beams and gravity manipulators, and the ability to manhandle large objects in space and move them into more desirable orbits present significant technical challenges. Once developed, however, these new technologies will, in effect, change our lives, as military and commercial spin-offs and dual-use capabilities from these new technologies will dramatically stimulate the global economy. As deep-space detection allows us to reflect, we may find answers to energy shortages and sources of dwindling critical resources.

It is conceivable that not only would the PDS serve as a defensive system for EMS protection, it also could be used to maneuver selected asteroids into stable earth orbits for various operations. A particularly interesting benefit involves mining asteroids for their rich deposits of metals and other valuable minerals. A thought brings into focus a space mining company making frequent trips into space to mine the asteroid that presented the original global threat. Further, controlled asteroids could be used as space bases or platforms for space stations or space colonies. Indeed, such possibilities would enhance the attractiveness of the PDS effort due to their economic potential.

Chapter 5

Recommendations

As we bring our discussion to a close, we issue the recommendations that follow. We also advance the caveat that simply because meteorologists include no data regarding planetary defense in their evening forecast is no reason to disregard or minimize such a significant issue.

Benefits

The Planetary Defense System (PDS) will provide a functional defensive capability against threat objects from space by 2025—a capability that may prevent catastrophic destruction and loss of life and even save the human race from extinction. Obviously, there is no guarantee that an asteroid or comet will pose a threat before, during, or even after this time frame, but, in any case, the global community will be prepared once the PDS is developed and deployed. The previous chapter also listed numerous dual-use benefits for the PDS.

Issues

Although promising signs exist in terms of more frequent workshops, technical discussions, and increased international cooperation, we must address several issues to resolve the planetary defense problem by 2025. First and foremost, does the global community believe that an unacceptable risk to the EMS exists, and, if so, is it committed to developing a solution? Obviously, the concepts presented in this paper require many new technologies that will take much time, talent, and resources to develop. Commitment does not equate to paper studies alone—it must be supported by substantial research and funding for these studies to be followed up with action. In an era of declining budgets, this issue presents a significant dilemma for leaders across the world. It should be remembered, however, that the threat of nuclear war was uncertain and even improbable during the cold war period; yet, the US spent more than $3 trillion over this 50-year time frame to maintain its strength against this uncertainty. These authors suggest that one needs only to consider the potential catastrophic effects from a large (>1 km diameter) ECO impact to conclude that humanity has a moral obligation to protect humanity.

Second, once a PDS becomes functional, especially if nuclear weapons are used, who controls it? Is it the United States, the United Nations or, perhaps, a consortium of world leaders that contributed to its development? These authors contend that the UN should be the controlling authority for the PDS. We acknowledge that such countries as the US, Russia, China, and possibly members of the European Union should carry greater weight and provide primary leadership for an effort of this magnitude. To gain the support of other nations, however, it will likely be necessary to use the UN as the controlling authority.

Third, some alternate future worlds developed during the ***2025*** study present a bleak outlook for enhanced technical development and resourcing during the next 30 years. Although these worlds are not predictive in nature, they do highlight that, if global conditions do not favor large monetary expenditures and committed focus on technical development, including the US itself, needs and ideas will never result in the required technologies to support a PDS.

Investigative Recommendations

The planetary defense problem is real and deserves serious attention. In this regard, we provide the following recommendations.

1. It is imperative that the global community unite to discuss, debate, and agree upon a plan to deal with the planetary defense problem. The participation by an increasing number of countries during technical workshops is highly encouraging. However, it must be noted that this is only an initial step in a long-term process. It is recommended that these workshops continue at all costs, since they require commitment and support by all nations.

2. Recommend that a team of engineers and scientists from the US, Russia, China, and the European Union brief Congress on the results of the planetary defense studies, emphasizing the ECO threat, by Spring 1997. Additionally, to garner support from other countries, recommend that this team, led by the deputy undersecretary of defense for space and the deputy director of space policy, present the planetary defense topic at a future combined session of the United Nations, preferably within the same time frame. Hopefully, such an effort will lead to a cooperative spirit among these nations.

3. Working closely with other nations, recommend that the US take the lead in developing and executing a program to educate the public about the ECO threat problem. This program is not intended to create anxiety or panic; rather, it seeks to reduce them through increased awareness. As discussed earlier, television documentaries and such computer links as the Internet will serve as the best educational media. Properly developed and presented, these tools would also serve as means of increasing support for further research, resourcing, and, ultimately, the development of a PDS.

4. We recommend the formal establishment of a global PDS consortium, perhaps at the next ECO workshop or during the proposed UN session, to commit required research and development funds for initial studies and PDS strategy development that will be required for the ultimate production of a three-tier PDS for EMS defense against ECOs. As a sign of good faith, we also recommend that the US immediately restore the $20 million to support *Clementine II* and sign-on as a primary stockholder for planetary defense.

5. Recommend that a phased acquisition strategy be adopted and implemented, leading to the ultimate development and deployment of a complete three-tier (consisting of detection, C^{4}I, and mitigation subsystems at each tier) PDS by 2025. For the near term, recommend that most of the available resources be used to upgrade detection capabilities worldwide, enabling scientists to more efficiently detect, and classify unknown ECOs.

Historically, humankind has used ingenuity and cunning to develop solutions to life-threatening challenges. Some of these threats have been immediate; others possible but not probable; and still others extremely remote. But, although planetary defense falls into the latter category, one must consider the extreme consequences that would likely result from an ECO impact. The issue is not *if,* but *when* an asteroid or comet will suddenly be detected as an EMS threat, causing global chaos and panic and ultimately placing all of humanity at risk. Obviously, our forefathers thought highly enough about our species to invest in capabilities to ensure its survival. The obvious question, then, is, Do today's leaders possess the same conviction towards preserving the human race, and, are they willing to invest in the PDS as a "catastrophic health insurance policy" for planet earth?

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APPENDIX A
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